NAVAL POSTGRADUATE SCHOOL
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THESIS

ANALYSIS OF ANTARCTIC REMOTE-SITE
AUTOMATIC WEATHER STATION DATA FOR PERIOD
JANUARY 1979 - FEBRUARY 1980

by

Kurt Michael Scarbro

June 1982

Thesis Advisor: R. J. Renard

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The second generation of the Stanford University developed Automatic Weather Station (AWS-2A) was placed at seven remote locations in the Antarctic in early 1979. Data transmissions were received via the NIMBUS VI platform from the Goddard Space Flight Center. Quality and amount of data received from the seven stations varied greatly, with many periods of sporadic reporting or none at all. The processing of the data from mid

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Analysis of Antarctic Remote-Site Automatic Weather Station Data for the Period January 1979 - February 1980

by

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The second generation of the Stanford University developed Automatic Weather Station (AWS-2A) was placed at seven remote locations in the Antarctic in early 1979. Data transmissions were received via the NIMBUS VI platform from the Goddard Space Flight Center. Quality and amount of data received from the seven stations varied greatly, with many periods of sporadic reporting or none at all. The processing of the data from mid January 1979 to early February 1980 was done with the goal of determining its credibility and its usefulness to the United States Antarctic mission as managed by the National Science Foundation. Various statistical measures were applied to the reported meteorological observations of surface pressure, wind and ambient air temperature, following closely the approach used by Renard and Salinas on AWS-1 data in 1976-1977. Emphasis was also placed on AWS-2A contributions to identifying mesoscale features around McMurdo Sound, Antarctica. Also discussed are two Adrams Buoy sites, set up as interim observation platforms between the AWS-1 and AWS-2A deployment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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I. INTRODUCTION

The Automatic Weather Station (AWS) for the Antarctic was initially described by Renard and Salinas (1977). That study dealt with the installation and operation of an AWS prototype station (AWS-1) at three locations in the Antarctic over the period February 1975 to May 1977. The AWS was designed to operate under the harsh conditions of the Antarctic climate; its development has been funded by the National Science Foundation (NSF) with primary technical and maintenance support from Stanford University, Palo Alto, California.

An initial network of Automatic Weather Stations, designated as AWS-2A stations, was established during the austral summer of 1978-1979 under the direction of the NSF working in conjunction with Stanford University, the Naval Support Force Antarctica (NSFA), the Naval Postgraduate School (NPS) and others. There followed a period of further experimentation on optimal positioning and proper maintenance of an AWS network and utilization of its data.

This report deals with the January 1979 to February 1980 time frame. The period represents a specific era for the AWS in that seven AWS-2A stations were deployed and the reporting of those stations was done through the NIMBUS VI Random Access Measurement System (RAMS).

It should be further noted at the outset that the AWS concept is an evolving system, with the presently deployed

stations having a new electronic suite for data transmission through the TIROS-N/NOAA-6,7 satellites vice the NIMBUS-VI configuration of AWS-2A. Data from AWS-2B are not under consideration here.

II. PLATFORM AND INSTRUMENTATION

A. PLATFORM

The platform of the AWS-2A is essentially the same as the AWS prototype (AWS-1) reported by Renard and Salinas (1977). Experience with the AWS-1 deployment led to the elimination of two wind sensors and one pressure sensor. Thus, the horizontal spar at the top of the three-meter tower supports one wind sensor, one ambient air temperature probe and the omni-directional radio transmitting antenna (Fig. 1).

B. INSTRUMENTS

The instrumentation specifications are described fully in Renard and Salinas (1977). Amplifying remarks on the temperature, pressure and wind sensors follow.

1. Temperature

As with the AWS-1, the Platinum Resistance Temperature Sensor Model 101-10-A-3-B-3-2-0 manufactured by the Weed Instrument Company, Inc., Elgin, Texas is the ambient air temperature device. A problem with the feedback loop system continued the necessity for each AWS-2A to be individually calibrated by Stanford University engineers. The equipment temperature thermistor for the internal temperature of the electronic compartment is the same as on the AWS prototype.

2. Pressure

The pressure sensor chosen for the AWS-2A is the Digi-quartz Pressure Transducer Model 215A, manufactured by Paroscientific, Inc., Redmond, Washington. A problem with this unit is the large variance from unit to unit and the requirement that each unit had to be individually calibrated by the manufacturer.

3. Wind

The Aerovane Transmitter, modified Model 120, made by the Environmental Science Division of Bendix Corporation, Baltimore, Maryland was used on the AWS-2A.

III. DATA COLLECTION

A. DATA TRANSMISSION

Transmission of AWS-2A data via NIMBUS VI RAMS is adequately described by Renard and Salinas (1977) and in the National Aeronautics and Space Administration's (NASA) NIMBUS VI User's Guide (1975).

B. DATA PROCESSING

After initial processing of the RAMS data by the Meteorological Data Handling System (MDHS) at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Maryland, the AWS-2A reports were distributed primarily in line printer format on magnetic tape. Non-meteorological data such as station identification, date and time of observation, etc., were represented in a final processed form. AWS-2A equipment and meteorological data were encoded in word sets.

Initially, data received from GSFC were both in octal and decimal base. This mixture, often with duplication, continued until March 1979 when NASA notified users that all data would be henceforth disseminated in decimal format. A FORTRAN IV computer program similar to AWS-1 was used for the AWS-2A data with new engineering constants, all provided by Stanford University personnel.

IV. DEPLOYMENT OF AWS-2A

The National Science Foundation sponsored the installation of seven AWS-2A units during 1979, four of these (Marble Point, Minna Bluff, White and Ross Islands) satisfying both NSFA operational needs and NPS research requirements. (See Table I and Fig. 2 for site locations). One of the major considerations in locating the aforementioned four sites is the maximum distance for helicopter support from the main United States base at McMurdo Sound, Antarctica.

A. BYRD CAMP

In 1978 one AWS-2A was installed at Byrd Camp (80^{o}S 120^{o}W) located on Marie Byrd Land ice sheet, and another placed approximately two kilometers outside of the camp. Each unit acted as a backup for the other and satisfied data requirements for the Global Weather Year Experiment. Byrd Camp, unoccupied during the winter, is situated about 1500 km east of McMurdo and about 1000 km west of Siple, both typically winter-over stations. The ice sheet elevation at Byrd is approximately 1800 m above sea level.

B. DRY VALLEY (ASGARD)

This site in the dry valley region of Victoria Land, part of the Trans-Antarctic Mountains, is located at 77^{o}36'S, 161^{o}04'E in the Asgard Range, inland of New Zealand's Vanda Camp. During austral summers this area and other dry valleys

are extensively studied by scientists and thus an AWS was needed to provide a year round supply of basic surface meteorological data. The AWS-2A tower, at an elevation of 1750 m, is located about 65 km from McMurdo Sound and 15-20 km east of the Victoria Land ice sheet where the dry valley generally slopes northeastward down to the sea.

C. McMURDO SOUND

The remaining four stations were installed in a regional network centered about McMurdo Station. It was proposed that this network would aid in understanding the regional Ross Ice Sheet mesoscale circulations and additionally help operational personnel at McMurdo in forecasting local weather for support of scientific work. The augmentation of local visual aids with real-time wind, temperature and pressure data from the remote stations was a major factor in assigning locations, although made more difficult by logistical constraints in delivering and activating the AWS-2A stations. Since McMurdo Station did not have a real-time readout capability from the NIMBUS-VI RAMS it was initially hoped that line-of-sight (LOS) placement would allow direct high frequency radio (RF) communications between the four AWS-2A sites and McMurdo. Shortly after installation and checkout, Stanford University technicians concluded that the RF noise interference which is normally prevalent in the Antarctic was too strong to allow successful LOS transmissions. Thus,

real-time AWS-2A data were unavailable to McMurdo and data for the time frame of this report were passed through GSFC to users. McMurdo Station did not receive any of the processed data for operational use during 1979 and early 1980.

1. Marble Point

The Marble Point AWS-2A was located in the same vicinity as the AWS-1 prototype in 1976 and early 1977 ($77^{o}26$'S $163^{o}45$'E). Located at an elevation of 40 m on glacial till at the end of the Wright (dry) Valley, this general location has been used by NSFA personnel, through visual sighting, to aid in local forecasting.

2. Minna Bluff

The Minna Bluff AWS-2A site is located on the Ross Ice Shelf to the north of the Bluff ($78^{o}25$'S $166^{o}54$'E at 20 m elevation). Placement in this particular location was intended to provide a clear LOS to McMurdo Station for the RF transmission of real-time data, avoiding interference from Black or White Islands. Minna Bluff is situated approximately due south of McMurdo and occasionally falls under the influence of katabatic winds from the interior. Moreover, it is on the approach line for much significant weather in the McMurdo Sound area. Like Marble Point the area of the site has been used by NSFA personnel, through visual sighting, to aid in local forecasting.

3. White Island and Ross Island

The White Island AWS site also was considered to be on an axis of approaches for significant weather in the McMurdo area. Situated on the Ross Ice Shelf at $77^{o}54'S$ $167^{o}51'E$, at an elevation of 20 m, this site is the closest of the four to McMurdo Station. The site on Ross Island is at an 850 m elevation located on the southern side of the island at $77^{o}36'S$ $167^{o}49'E$ between Mount Erebus and Mount Terror. Both Ross and White Island sites were placed with LOS considerations.

V. DATA EVALUATION

From the outset it must be noted that data from several of the AWS-2A during the January 1979 to February 1980 time period were characteristically sporadic and many times non-existent (Fig. 3). Because of this fact, the contribution made by these data toward a regional climatology is minimal. However, the Renard and Salinas evaluation (1977) demonstrates the reliability of the AWS platform and its intruments and it was the opinion of the engineering staff at Stanford University that measurements provided via AWS-2A are comparable, if not better, than conventional synoptic observations of wind, temperature and pressure.

In evaluating these data the main thrust was directed at applying basic statistical procedures that would evolve a general meteorological picture of each of these remote sites. Primary texts used as a basis for computations are Brooks and Carruthers (1953) and Panofsky and Brier (1958). Comparisons were made to the synoptic surface observations of McMurdo Station during the same period and also to available Antarctic climatology (U.S. Naval Weather Service, 1970), with emphasis on the local McMurdo area.

Data were processed by station for monthly, seasonal and annual statistics, as appropriate. The following outlines the evaluations completed for both meteorological data and other factors at each site. Quality control measures were

applied to all reports to eliminate or adjust those apparently in error.

A. WIND

1. Resultant wind direction and mean vector wind speed,
2. Mean scalar wind speed,
3. Frequency of wind directions and speeds,
4. Wind persistence $(P = \frac{\text{Mean vector wind speed}}{\text{Mean scalar wind speed}})$, and
5. Prevailing wind directions.

B. TEMPERATURE

1. Monthly mean,
2. Average daily maxima and minima,
3. Monthly range, to include extreme monthly maximum and minimum, and
4. Diurnal temperatue variation.

C. PRESSURE

1. AWS-2A surface pressures compared to sea-level pressures observed at McMurdo Station,
2. Time differences of pressure for interpolated values as well as the standard deviation of these differences,
3. Time lag of significant pressure-data points (e.g., extreme low pressure) between AWS-2A sites.

D. NATURE OF AWS REPORTING (See Appendix A)

1. Number and percentage of possible AWS-2A reports which were transmitted and received,
2. Number and percentage of possible AWS-2A reporting days represented,
3. Frequency table of valid AWS-2A reports by station and time periods, and
4. Recurrent errors, generating either by the AWS-2A station or by the satellite platform.

Comparisons of AWS-2A data to those from McMurdo should be made with several considerations. McMurdo reporting is subject to human, mechanical and electronic error, as with any synoptic observations. The McMurdo data did not undergo quality control. One must also consider the differences in location between all remote sites and McMurdo (Table I and Fig. 2). Other factors which affect the data and comparisons are the lack of calibration checks during the long winter period when the sites cannot be visited and the use of a linear interpolation scheme between AWS-2A observations in order to facilitate the comparison of site reports to McMurdo's three-hourly observations.

The following seasonal definitions are used in describing the data results:

Summer	--	December and January
Autumn transition	--	February and March
Winter	--	April through September
Spring transition	--	October and November

These seasons are based on a description in the Antarctic Forecaster's Handbook (U.S. Naval Weather Service, 1970).

VI. RESULTS

A. WIND

1. Annual Wind Analyses

a. McMurdo Station: 2382 Observations

The United States Navy's McMurdo Station takes observations at 3-hour intervals throughout the year; thus, the number of observations used here represent 82% of the total possible number (2920) for a complete 365-day year.

Figure 4b indicates that the wind field for 1979 at McMurdo Station is fairly representative of climatology (U.S. Naval Weather Service, 1970). The maximum reported wind speed is 19 m s^{-1} and approximately 60% of the reported winds are from the E-NE sectors. There is no indication of katabatic winds having a significant effect on McMurdo Station.

b. Ross Isle (ID #0017): 747 Observations

This station has the second highest number of AWS-2A wind reports for 1979. Figure 4c shows that 40% of all reports were from the northeast with a maximum velocity of 18 m s^{-1}. Located on a mountainside, observations at this site appear to be highly influenced by local effects with the winds channeling through the N-S gap between Mounts Erebus and Terror. Also, the tower was virtually buried, apparently near the end of 1979, with the Aerovane Transmitter less than

a meter above the snow cover, a consideration necessary for the proper interpretation of vector wind observations.

c. Marble Point (ID #0327): 576 Observations

This station has the most uniform wind distribution of all the AWS-2A sites during 1979 with no sector above 20% frequency (Fig. 4d). Marble Point's locale near the eastern end of a dry valley probably accounts for the high winds of 25 and 22 m s^{-1} from the west and northwest, respectively. However, it is to be noted in Fig. 4d that the frequency of winds greater than 10 m s^{-1} is not dominated by the west and northwest sector but is evenly distributed about the compass rose.

d. Asgard (Dry Valley - ID #0533): 780 Observations

This site has the greatest number of AWS-2A reports during 1979. Katabatic winds and local effects dominated this station's wind field. Very high winds, i.e. maximums of 44 and 32 m s^{-1}, were reported from the south and southeast, respectively (see Fig. 4e). Located on a ridge at the beginning of a dry valley, near the Victoria Land ice sheet, strong winds from the interior readily reach this site and are probably channeled down the dry valley below the site where local geographic effects direct the surface flow toward the north.

e. Byrd Camp (ID #0021): 371 Observations

The Antarctic Forecaster's Handbook (U.S. Naval Weather Service, 1970) shows that Byrd Camp has predominantly northerly winds throughout the year with a very small percentage of winds from the southern semi-circle. Figure 4f shows a similarly strong northerly wind field during 1979 at Byrd. Approximately 65% of all wind observations are from the north, at speeds up to 37 m s^{-1}. Located in a flat and open area away from the camp, the AWS-2A site has the smallest percentage of calm conditions. The other Byrd AWS-2A station (ID #1403) did not transmit any useful wind data.

f. Minna Bluff (ID #1544): 53 Observations

Located on the Ross Ice Shelf, Minna Bluff AWS-2A shows the most direct correlation with katabatic winds off the continent. Winds greater than 10 m s^{-1} are predominantly from the south and southwest, accounting for 55% of the reported winds. Figure 4g shows maximum wind speeds of 41 and 27 m s^{-1} from the south and southwest, respectively. Minna Bluff lost its Aerovane propeller between 0215 GMT 27 February and 0048 GMT 28 February with the last recorded wind speed being 41 m s^{-1}.

g. White Island (ID #0311): 81 Observations

Only 81 observations are available from the White Island AWS-2A site during 1979 (Fig. 4h). The reported winds are well distributed about the wind rose with 49% of the

reports classified as calm. The sparsity of data prevents any meaningful analysis at this station.

Only three stations provided some data in January 1980, namely Asgard, Ross Island and Byrd Camp (ID #1403). Asgard reporting was normal with no problems, Byrd had no wind speed data and the Ross Island station had unreliable wind, pressure and temperature reports after 18 January 1980. The site at Ross Island may have malfunctioned due to drifting snow and a complete burial of the electronics box.

2. Seasonal Wind Analyses

Seasonal winds were considered for those stations for which there existed sufficient data to obtain meaningful results. The seasons of summer, fall, winter and spring were defined in Section V.

a. Autumn Transition 1979 (Figures 5a-5e)

McMurdo is dominated by easterly and southeasterly winds and Ross Island by northeasterly and northerly winds. Marble Point shows strong southerly wind direction dominance during fall, contrasting this site's uniform distribution of winds for the year. Asgard also displays a dominance of southerly winds. There are few AWS-2A observations from the remaining stations during this time frame.

b. Winter 1979 (Figures 6a-6f)

McMurdo maintains easterlies as the most frequent direction, with the secondary maximum frequency northeast

vice the southeast winds of fall. Ross Island displays mostly northeast and northerly winds, similar to the station's characteristics throughout the year. During the winter, Marble Point returns to a wind field very uniform in frequency about the compass rose. The AWS-2A station at Asgard, with a winter total of 404 reports, shows southerly and southeasterly winds with a maximum speed of 34 m s^{-1}. Byrd site (ID #0021) displays a strong preference for northerly winds with approximately 25% of the winds greater than 10 m s^{-1} from that direction.

c. Spring Transition 1979 (Figures 7a-7e)

In winter, data are non-existent for the most part at White Island, and data for wind speed and/or direction are missing at Minna Bluff. McMurdo continues to show a large frequency of easterly winds; Ross Island and Marble Point reports indicate mostly light winds during the spring season. Of the AWS-2A stations with spring reports, only Asgard displays any significant frequency of winds equal to or greater than moderate strength (6-10 m s^{-1}). Not enough observations exist elsewhere for meaningful analysis.

d. Summer 1979-1980 (Figure 8a)

Only the Asgard site has a sufficient number of summer reports (221) to provide any meaningful results. The dry valley has over 40% of its wind reports from the south, with a 16 m s^{-1} maximum wind speed.

3. Monthly Wind Analyses

For the monthly analyses described below, a minimum of 30 wind reports was required at each site. It is recognized that due to the reporting characteristics of the NIMBUS-VI RAMS and AWS-2A these 30 or more reports do not necessarily represent the complete month, but may be from only a small number of days in the month.

a. Prevailing Winds and Common Wind Speeds

Table II lists the monthly prevailing wind direction and modal speed for McMurdo Station and the four AWS-2A locations, Ross Island, Marble Point, Asgard and Byrd (#0021), during the period mid-January to December 1979. All stations in the McMurdo region show prevailing wind directions primarily from the eastern semicircle with Marble Point displaying the greatest variability. Byrd (#0021) shows prevailing northerly winds and relatively high wind speeds (8-25 m s^{-1}). Although very limited in data, Minna Bluff data indicate a prevailing south-southwest wind and a modal wind speed of 20 m s^{-1} during February 1979.

b. Resultant Wind, Scalar Mean Wind Speeds and Persistence

The resultant wind, or the mean wind vector, is obtained by resolving each wind report into components from the north and east, summing over a month, obtaining the averages, and reconverting the average components into a

single vector (Glossary of Meteorology, 1959). Persistence (also called constancy or steadiness) is defined as a ratio of the magnitude of the resultant wind to the average speed of the wind without regard to direction (scalar mean wind speed). Persistence gives a long-term quantitative value on the nature of the wind direction variability at a given location, in this case McMurdo and four of the AWS-2A sites for each month in 1979.

Table IIIa outlines resultant winds for the stations. McMurdo generally displays a resultant wind from the east or east-northeast with a mean speed of 3 to 4.5 m s^{-1}. Two months, February and June, have a mean direction from the southwest and west. The Ross Island site has resultant winds from the north to northeast sector with mean speeds of 1 to 3.4 m s^{-1}. Although the majority of the months in 1979 at Marble Point display a generally northeast mean direction, three of the months show a southwesterly resultant direction. Three months were not included in Table IIIa, due to a small amount of data, but they also indicate a southwesterly direction. Mean vector wind speed ranges from 0.4 to 4.7 m s^{-1} at Marble Point. Asgard shows a south-southwest resultant wind direction throughout the year with mean speeds of 1.1 to 5.2 m s^{-1}. Byrd (#0021) has a northerly mean vector direction with high mean vector speeds, 6.5 to 13.8 m s^{-1}. At Minna

Bluff during February 1979 (not shown in Table IIIa) the only month considered, the resultant wind is 197^{o} at 15 m s^{-1}.

Scalar mean wind speeds and persistence are listed in Table IIIb. Of particular note are the persistence values for McMurdo, which lie between 0.64 and 0.85, a range of 0.21 while the four AWS-2A sites have ranges of 0.28 at Asgard, 0.31 at Byrd (#0021), 0.43 at Ross Island and 0.79 at Marble Point. Asgard data indicate one month, May 1979, with 42 reports and a persistence of 1.00. Marble Point has an extremely variable ratio from month to month with August 1979, a month with 79 reports, having a persistence of 0.10. Persistence at the various sites shows no strong patterns, with monthly variations seemingly independent of season.

B. TEMPERATURE

1. McMurdo Station

Figures 9a and 9b show McMurdo Station air temperature statistics, both from climatology (U.S. Naval Weather Service, 1970) and the 1979 reported observations. The climatology is based on data from 1955 to 1967. In general, 1979 as a whole does not appear to be significantly anomalous even though the winter months, April through September 1979, do show both positive and negative anomalies up to several degrees in minimum, maximum and mean temperatures. The lack of one or two singularly cold months represents the coreless winter of the Antarctic, better shown by the climatology than

1979. The similarity of McMurdo's long-term climatology indicates that the McMurdo Sound area in 1979 experienced a typical year for surface air temperature. Both climatology and 1979 reports display a slight rise in the mean air temperature from May to June, and in 1979 only from March to April as well. Similar characteristics, except for the March to April warming, are noted from an analysis of the regional AWS-2A sites, which follows.

2. Ross Island (ID #0017)

The Ross Island AWS-2A site, at an elevation of 800 m, shows quite consistently lower mean temperatures than McMurdo throughout the year, with some exceptions in May and August. This relationship occurs during all months, without regard to the number of reporting days. Figure 9c shows Ross Island-air temperature statistics for 1979.

3. Marble Point (ID #0327)

Like most other stations in the area, this AWS-2A site displays the June mid-winter warming, as represented by the mean temperature. The coreless winter is shown well by the fact that May, July and August all have similar mean temperatures during 1979. Marble Point tends to have mean temperatures closer to those of McMurdo than the other AWS-2 locations. The similarities of locales, on promontories near sea level along McMurdo Sound probably contribute to the close comparisons. Marble Point is the only AWS-2A site to

display a warming in the mean temperature from March to April. Figure 9d shows this site's temperature ranges.

4. Asgard (ID #0533)

A temperature profile similar to McMurdo is shown for this dry valley station in Figure 9e. A June absolute minimum of -65^{o}C is probably incorrect. For Asgard, at an elevation of 1750 m, it is understandable that mean air temperatures are 5-10^{o}C lower than at McMurdo. As with McMurdo synoptic observations and Ross Island and Marble Point AWS-2A reports, Asgard also experiences a rise in the mean temperature from May to June.

5. Minna Bluff (ID #1544)

Data from this AWS are very scattered and the only concentration of temperature reports is in June. Even though the data are sparse, Figure 9f indicates that Minna Bluff also experiences the mid-winter warming in June 1979. In general, Minna Bluff appears to be approximately 5^{o}C colder than McMurdo Station, possibly due to its more exposed poleward location on the Ross Ice Shelf.

6. Byrd Camp (ID #0021 and ID #1403)

a. Byrd Climatology

The Antarctic Forecaster's Handbook (U.S. Naval Weather Service, 1970) shows the coreless winter of the Antarctic interior quite vividly (Figure 9g). In the figure one can see that four months, June-September, have

essentially equal mean monthly temperatures. Another characteristic that this interior camp shows is the large temperature drop between February and March, and the large rise between October and November. This aspect of the coreless winter phenomenon also occurs in the McMurdo region both in climatology and the AWS-2A sites in that area (see Figures 9a through 9f).

b. Byrd AWS-2A Sites

Byrd AWS-2A sites both display similar temperature trends in 1979 (Figures 9h and 9i), with a warming from May to June and a minimum mean temperature in August. The high percentage of days represented in July and August reports at sites #0021 (77% and 87%, respectively) and #1403 (84% and 87%) give credibility to the fact that the winter of 1979 at Byrd Camp is somewhat colder than climatology. In general, both AWS-2A sites show a 1-12°C lower mean temperature than climatology throughout the winter, and both stations show a very cold August (12°C lower at #0021 and 10°C lower at #1503), giving a variation from the long-period coreless winter. Differences between the two Byrd AWS-2A sites are probably due to different sampling days and the number of reports processed at the Goddard Space Flight Center.

7. Diurnal Temperature Variations

For most of the year at the Antarctica remote AWS-2A sites, the sun remains either above (Oct-Feb) or below (Apr-Aug) the horizon during a 24-hr period. In the summer period, there is a diurnal variation in the sun's above-horizon altitude and a corresponding variation in temperature, however small. As a result, one expects some diurnal variation of Antarctic temperatures but much less than that in the temperate regions. Figures 9a through 9i give mean daily minima/maxima and although not a direct indication of diurnal variation it provides an impression of the extent of diurnal differences. Unexpectedly, some of the largest diurnal variations occur in winter, probably related to variations in the wind speed/direction. While McMurdo, in both climatology and in the 1979 synoptic observations, has a 5-10^{o}C difference between the daily means of maximum and minimum temperature, all of the AWS-2A sites reported a much smaller range between the two values. The Byrd climatology vs AWS-2A data shows a similar relation. Absence of sampling at exact maximum/minimum temperature times for the AWS probably accounts for most, if not all, of these differences.

C. SURFACE PRESSURE

1. Introduction

Surface pressure is reported by an AWS-2A site with no adjustment for elevation. Still it is felt that a

correlation of the surface pressures at the AWS-2A stations and the sea-level pressure at McMurdo Station is helpful in determining the validity of the remotely reported pressures. The correlations computed in this study do not include the Byrd Camp AWS-2A sites.

Three time periods were selected to determine the evaluations. The periods 19-22 December 1979, 05-09 June 1979 and 24-27 October 1979 represent periods of rapid pressure changes, with well-defined times of peak pressure in the McMurdo Sound area. These periods are representative of three seasons: summer, winter and spring transition. Also, the periods selected have a large and continuous number of pressure reports with few breaks, thereby providing a suitable data base for interpolation and correlation. Figs. 10, 11 and 12 provide an overview of the synoptic situation during the three time periods as analyzed by McMurdo Station personnel. The absolute change in sealevel pressure at McMurdo during the above periods was recorded at 16 mb, 25 mb and 15 mb, respectively.

2. Surface/Sea-Level Pressure Correlations

All correlations of pressure from McMurdo and AWS-2A sites were carried out using a correlation program from the University of California (Los Angeles) Bio-Medical Program (1979). The computed correlation coefficient is

$$R = \frac{(x_j - \bar{x})(y_j - \bar{y})}{\Sigma((x_j - \bar{x})^2 \Sigma(y_j - \bar{y})^2)^{1/2}}, \quad (1)$$

where x_j (y_j) is the AWS-2A (McMurdo) pressure at time j, $\bar{x}$ ($\bar{y}$) is the mean reported AWS-2A (McMurdo) pressure. Due to missing data at the AWS-2A stations and a three-hour data interval at McMurdo, a linear interpolation of AWS-2A pressure values became necessary.

a. Summer Comparison

Figs. 10a-d are the operational sea-level pressure analyses from McMurdo Station. Pressure data show that McMurdo experienced a slight rise in sea-level pressure from 19 to 20 December 1979 followed by a steady decrease through 22 December. Calculations from the McMurdo and AWS-2 pressure data produced the following correlation coefficients:

Ross Island	- .97
Marble Point	- .91
Minna Bluff	- (no data)
Asgard	- .99
White Island	- 1.00

b. Winter Comparison

Figs. 11a-d represent the surface synoptic situation, 5-9 June 1979, in the McMurdo area. Reports indicate that a previously stationary low pressure area moved north, away from McMurdo, on 6 June with a subsequent low pressure-frontal system moving into the area on 7 June. Using the

interpolated data, the following correlation coefficients were determined for each AWS-2A and McMurdo pressure-data set:

Ross Island	-	.92
Marble Point	-	.80
Minna Bluff	-	.81
Asgard	-	.97
White Island	-	(no data)

The relatively low correlation of the winter data, paragraph 2b above, for Marble Point and Minna Bluff is due to the lack of McMurdo pressure reports at the end of the time period (9 June). This prevented interpolation of a probable rapid fall in pressure in the region; instead a less rapid fall in pressure is reflected by the incomplete McMurdo, Asgard and Ross Island observations.

c. Spring Comparison

Figs. 12a-d show the McMurdo surface synoptic situation, 24-27 October 1979. Pressure data show a drop in sea-level pressure from 24 October to 26 October, with the low center remaining over the McMurdo area on 26-27 October followed by a steady rise in pressure on 28 October. During this time frame the following correlation coefficients were computed using data from McMurdo and the remote sites:

Ross Island	-	.98
Marble Point	-	.99
Minna Bluff	-	(no data)
Asgard	-	.99
White Island	-	(no data)

VII. FINAL REMARKS

During the deployment period of AWS-2A, with data received via NIMBUS-VI RAMS, the groundwork was established for the management of remote-site automated weather observations in Antarctica. Stations such as those at Asgard and Marble Point show good reliability in reporting data, and the available data show every indication of excellent quality. Data agreed well when compared to climatology for the seasonal and monthly trends and also when compared to conventional observations from McMurdo Station.

The data analyzed in this report represent an initial rough cut at determining accuracy of the three major weather parameters (pressure, temperature, wind) in an Antarctic AWS network. With judicial selection of the AWS-2 stations and increased responsiveness through the operationally oriented TIROS-N Data Collection System, the AWS-2 sites should provide excellent data for both operational forecasters and researchers working in Antarctica. Since the period covered in this report, real-time AWS data have become available to the Naval Support Force Antarctica Weather Center at McMurdo.

APPENDIX A: NATURE OF AWS-2A REPORTING

Reporting statistics of the AWS-2A sites during the period of this study were affected by several factors. One of these factors is the performance of the Random Access Measurement System (RAMS) on board the NIMBUS VI spacecraft. RAMS had no known problems of malfunctions and was considered to be operating normally throughout the reporting period. Because of the inclination of the orbital path, NIMBUS VI had the ability to provide between 10-14 passes per day over the Antarctic AWS-2A sites. Depending on the line-of-sight (azimuth and elevation of the satellite) from the AWS-2A site, a data stream of 2 to 10 samplings per pass could be obtained.

1. The most important factor in successful reporting is the quality of the data transmissions from each AWS-2A station. As long as the meteorological instruments were performing well, a data stream of 2-10 samplings per pass would normally provide enough information to extract an acceptable report for the time frame of the pass. Other factors include probable radio frequency interference, which is common in Antarctica, and processing, archiving and retrieval by GSFC.

2. Paragraph D, Section V outlines the major points of AWS-2A reporting that are pertinent to this study. Tables IVa through IVg list each station, with a breakdown by the number and percentage of possible report days and the number

and percentage of expected reports which were transmitted, as based on 12 reports/day possible. Further, the number of reports by station and three-hour time periods centered around 0000, 0300, 0600,...2100 GMT shows a distinct maximum in reporting at 0900 GMT and a minimum at 0000 GMT (Table V). These maximum and minimum times were dictated by the orbital characteristics of the NIMBUS VI, a sun-synchronous orbit, that provided the McMurdo region with optimum line-of-sight between the AWS-2A's and the spacecraft near 0900 GMT. The fact that the Byrd sites, 1500 km east of McMurdo, show a similar frequency distribution to those near McMurdo is primarily a function of the satellite's sub-point track across the Antarctic Continent and the omni-directional nature of the RAMS system.

APPENDIX B: ANTARCTIC ADRAMS BUOYS - 1979

During 1979, two Adrams buoys equipped with pressure and air-temperature instruments, were placed by helicopter in the vicinity of two of the deployed AWS-2A's. These air-droppable buoys have long been used in the harsh polar environment of the Arctic, providing both meteorological parameters and sea/ice drift-tracking positional data. One of the Antarctic buoys was co-located with the Marble Point AWS-2A and the other on the northern side of Minna Bluff.

A. DATA COLLECTION

Data were collected from the buoys via the NIMBUS-VI Random Access Measurement System (RAMS), similar to the AWS-2A method. The RAMS is described in the NIMBUS-VI User's Guide (1975). The Adrams buoy is constantly transmitting, thus the satellite gains and loses contact depending on line-of-sight (LOS).

The Santa Barbara Polar Research Laboratory provided the information required for decoding the data provided by the MDHS of NASA's GSFC. This information included engineering coefficients for each buoy, equations for barometric pressure and internal temperature, and a non-linear calibration curve for air temperature.

Since both the Adrams buoys and the AWS-2A sites used the same spacecraft for reporting data, obtaining simultaneous

data from the sites was possible. This provides for direct correlation of the parameters with no interpolation required.

B. DEPLOYMENT

Initially the buoys were to be activated at the two locations in December 1977 as an interface until the AWS-2A stations were ready for deployment in December 1978. Although the buoys were in place during 1978, no data were transmitted due to lack of batteries and electrical power. Thus, the desired intent of exercising the data handling process between NSFA, NPS and NASA's GSFC prior to the AWS-2A network deployment in 1979 was not fulfilled. As with the AWS-2A location choices, Marble Point and Minna Bluff represent areas the McMurdo forecasters use for visual weather inputs. They are areas from which deteriorating conditions often approach the McMurdo operating area.

The Marble Point Adrams buoy was co-located with the AWS-2A at $77^{o}26'$S, $163^{o}45'$E. While the Minna Bluff AWS-2A was located on the Ross Ice Shelf, the Adrams buoy was placed on the bluff itself at $78^{o}27'$S, $165^{o}45'$E, approximately 25 km west of the AWS-2A and about 100 m elevation vice 20 m (Fig. 2). While the AWS-2A sensors were located from 1.5 m (pressure) to 3 m (wind and temperature) off the ground, the Adrams buoy and its instruments were within one-half meter of the surface.

C. RESULTS

1. Reports

a. Marble Point Adrams Buoy

Data were received sporadically from 04 February to 14 April (70 days). Seven satellite passes during a day appear to be a maximum and like the Marble Point AWS-2A the period of 0000-0600 GMT represents a time frame of minimum reporting. The maximum frequency of reports appears around 1000 and 2100 GMT for this Adrams buoy site (0900 and 1500 GMT at the AWS-2A).

b. Minna Bluff Adrams Buoy

Data were received for 04 February to 04 March 1979 (29 days) with characteristics similar to those mentioned above. Like the Minna Bluff AWS-2A the highest frequency of reports occurred around 0900 and 1200 GMT, with minimums from 0000 to 0600 GMT.

c. Conclusion

As with the AWS-2A sites, the orbital path of the NIMBUS-VI was optimal for reports at 0900 GMT and minimal for those at 0000 GMT. The small number of reporting days for each Adrams site was a function of the amount of data requested through NASA's GSFC due to quality of data from the buoys, as covered in the following sections.

2. Temperature

The reported ambient air temperatures were totally unreliable for each Adrams site. While the Marble Point AWS-2A reported average February and March temperatures of $-8^{o}C$ and $-15^{o}C$ respectively, and the Minna Bluff AWS-2A reported a February average of $-10^{o}C$, both Adrams buoys generally registered temperatures of $+14.7^{o}C$ or $+14.5^{o}C$ and sporadically $-23^{o}C$ and $-40^{o}C$. Thus, the temperature reports from the Adrams site were considered completely inaccurate.

3. Pressure

a. Marble Point Adrams Buoy

A comparison of the Adrams pressure reports with those of the AWS-2A at Marble Point was very favorable. The Adrams always reported a lower pressure, averaging 1.35 mb lower, with variations from the Marble Point AWS-2A pressure ranging from 0.64 mb to 2.23 mb. Of interest is the increase in the amount of pressure difference with time between the Marble Point Adrams and AWS-2A, i.e. 0.9-1.0 mb on 04 February 1979, 1.2-1.4 mb on 04 March 1979 and 2.0-2.2 mb on 03 April 1979.

b. Minna Bluff Adrams Buoy

A comparison of the Adrams pressure reports with those of the AWS-2A at Minna Bluff is difficult to judge due to the separation of the two sites in distance and elevation. A coarse comparison of the pressure data indicates that the

difference varied between 46.93 and 50.35 mb, with a mean difference of 48.74 mb, for 26 reports. For fifteen of these reports, the differences are within one standard deviation (1.05 mb) from the mean.

D. CONCLUDING REMARKS

While the Adrams' surface temperature observations proved totally unreliable, the pressure data appear to be accurate in relation to the AWS-2A pressure reports. Deployed as a stop-gap measure during 1978, but not activated until 1979, the buoys provide some indication of the consistency of the AWS-2A pressure sensor and reports. With the deployment of the AWS-2A network and the cumbersome nature of receiving the RAMS processed data for both the AWS-2A and the Adrams buoys, no data were retrieved after the Fall Transition in 1979 and efforts were turned exclusively to the AWS-2A. During the 1979-80 austral summer the buoys were removed from their sites.

TABLE I. AWS-2A Station Information

STATION	NIMBUS VI RAMS ID	LATITUDE	LONGITUDE	ELEVATION	DISTANCE/BEARING FROM McMURDO
ASGARD	0533	77°36' S	161°04' E	1750 M	141.2 KM/265°00'
MARBLE POINT	0327	77°26' S	163°45' E	40 M	83.3 KM/301°03'
MINNA BLUFF	1544	78°25' S	166°54' E	20 M	64.0 KM/176°18'
ROSS ISLAND	0017	77°36' S	167°49' E	800 M	37.7 KM/044°19'
WHITE ISLAND	0311	77°54' S	167°51' E	20 M	27.5 KM/103°52'
BYRD	0021	80°00' S	120°00' W	1800 M	N/A (2 KM FROM BYRD CAMP)
BYRD	1403	80°00' S	120°00' W	1800 M	N/A (AT BYRD CAMP)

TABLE II. Monthly Prevailing Wind Directions and Most Frequently Observed Wind Speed (m/sec) at AWS Stations and McMurdo - 1979.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
McMurdo	E/5	E/5	E/4	E/3	NE/8*	E/6*	E/8*	NE/2*	ENE/6*	E/3*	E/5	ENE/6
Ross Island	-	ENE/1*	NE/6	NNE/3	NNE/3	NE/3	NNE/1	NNE/3	N/3	NNE/3	NNE/2	NE/1
Marble Point	-	SSE/6	W/1*	-	-	ESE/4*	NNE/3*	ESE/3*	N/6	NNW/3*	SSE/1	ESE/3
Asgard	-	S/3*	S/4*	SSE/3*	SE/1*	SSE/3*	SE/1*	SE/1*	SSE/1*	SSW/1*	SSW/1*	S/3
Byrd(0021)	-	-	N/10	N/25	N/12	N/20	N/9	N/12	N/10	N/8	-	-
Minna Bluff		SSW/20										

Notes: 1. Minimum of 30 wind reports in a month regardless of spacing of reports.
2. Most frequent speed (to within $\pm$ 1 m/sec) includes all directions.
*3. Most frequently reported condition is calm.
4. Number of monthly reports by site in Table IV in No. of Rpts Received column.

TABLE IIIa. Monthly Resultant Winds at AWS-2A Stations and McMurdo - 1979.
(Deg/m s^{-1})

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
McMurdo	79°/3.1	239°/4.5	81°/4.5	81°/4.0	64°/3.5	269°/3.7	72°/3.4	56°/3.2	68°/3.9	71°/2.8	84°/2.8	51°/3.2
Ross Island	-	16°/2.5	26°/3.4	22°/2.0	30°/2.9	26°/1.6	37°/2.0	31°/3.0	21°/2.1	18°/2.2	1°/1.3	52°/1.0
Marble Point	-	202°/4.7	61°/1.1	-	-	261°/0.8	67°/1.5	261°/0.4	21°/1.5	55°/0.7	73°/0.5	13°/1.6
Asgard	-	198°/4.9	185°/5.2	186°/4.0	206°/1.1	205°/4.4	203°/2.6	209°/4.6	191°/5.0	194°/2.3	187°/2.8	280°/2.2
Byrd (0021)	-	-	0°/7.7	10°/13.5	31°/7.5	11°/13.8	2°/7.2	16°/9.0	1°/6.5	4°/7.1	-	-

TABLE IIIb. Scalar Mean Wind Speeds (m s^{-1}) and Persistence - 1979

McMurdo	4.5 P = .68	6.8 .66	5.7 .79	5.6 .71	4.5 .78	5.1 .72	4.0 .85	4.0 .81	5.2 .75	3.5 .81	4.4 .64	4.3 .73
Ross Island	-	4.5 P = .57	4.1 .84	3.3 .61	3.1 .93	3.2 .50	2.5 .80	4.1 .74	3.1 .68	2.5 .87	2.4 .55	1.3 .74
Marble Point	-	5.3 P = .89	3.4 .32	-	-	3.3 .23	3.4 .44	3.9 .10	5.3 .28	2.6 .29	3.1 .16	4.3 .38
Asgard	-	6.0 P = .81	5.8 .89	4.5 .91	1.1 1.00	4.7 .94	3.6 .72	5.2 .87	5.7 .87	2.8 .82	3.8 .73	3.6 .62
Byrd (0021)	-	-	10.9 P = .70	13.9 .97	11.4 .66	15.0 .92	7.5 .96	10.3 .88	8.3 .78	7.6 .93	-	-

Note: For number of monthly reports by site, see column labeled "No. of Rpts Received", in Table IV.

TABLE IV. No. of days/% of days: based on indicated period of data from AWS-2A. No. of reports/% of reports: based on an average maximum of 12 satellite passes per day.

Table IVa. Ross Island (0017)
Period of data: 23 Jan 79 - 02 Feb 80

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	5	56	7	6.5
FEB	17	61	48	14.3
MAR	16	52	54	14.5
APR	16	53	42	11.7
MAY	10	32	24	6.5
JUN	21	70	63	17.5
JUL	24	77	85	22.8
AUG	27	87	100	26.9
SEP	21	70	61	16.9
OCT	25	81	91	24.5
NOV	25	83	69	19.2
DEC	23	74	103	27.7
			747	

Initial Data on: 23 Jan 79
Final Data on: 02 Feb 80

Table IVb. White Island (0311)

Initial Data on: 29 Jan 79
Final Data on: 27 Dec 79

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	1	33	2	5.6
FEB	1	04	1	0.3
MAR	-	-	-	-
APR	-	-	-	-
MAY	-	-	-	-
JUN	-	-	-	-
JUL	-	-	-	-
AUG	-	-	-	-
SEP	-	-	-	-
OCT	1	03	2	0.5
NOV	13	43	31	8.6
DEC	19	70	45	13.9
			81	

Table IVc. Marble Point (0327)

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	6	46	13	8.3
FEB	17	61	50	14.9
MAR	13	42	35	9.4
APR	10	33	18	5.0
MAY	13	42	25	6.7
JUN	23	77	50	13.9
JUL	22	71	64	17.2
AUG	25	81	79	21.2
SEP	18	60	31	8.6
OCT	23	74	66	17.7
NOV	24	80	72	20.0
DEC	18	58	73	19.6
			576	

Initial Data on: 19 Jan 79
Final Data on: 24 Dec 79

Table IVd. Minna Bluff (1544)

Initial Data on: 24 Jan 79
Final Data on: 29 Sep 79

JAN	3	38	4	4.2
FEB	19	68	49	14.6
MAR	14	45	60	16.1
APR	16	53	47	13.1
MAY	19	61	48	12.9
JUN	25	83	76	21.1
JUL	4	13	10	2.7
AUG	-	-	-	-
SEP	5	17	20	5.7
OCT	-	-	-	-
NOV	-	-	-	-
DEC	-	-	-	-
			314	

Table IVe. Asgard (0533)

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	6	40	12	6.7
FEB	16	57	47	14.0
MAR	15	48	54	14.5
APR	16	53	36	10.0
MAY	19	61	42	11.3
JUN	26	87	73	20.3
JUL	24	77	87	23.4
AUG	29	94	108	29.0
SEP	21	70	58	16.1
OCT	25	81	90	24.2
NOV	25	83	71	19.7
DEC	23	74	102	27.4
			780	

Initial Data on: 17 Jan 79
Final Data on: 31 Jan 80

Table IVf. Byrd (0021)

Initial Data on: 08 Mar 79
Final Data on: 16 Nov 79

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	-	-	-	-
FEB	-	-	-	-
MAR	8	33	25	8.7
APR	13	43	33	9.2
MAY		39	19	5.1
JUN		53	41	11.4
JUL		77	81	21.8
AUG	27	87	96	25.8
SEP	15	50	28	7.8
OCT	16	52	45	12.1
NOV	2	7	3	1.6
DEC	-	-	-	-
			371	

Table IVg. Byrd (1403)

Initial Data on: 20 Feb 79
Final Data on: 02 Feb 80

Month	No. of Days with Reports	% of Possible Days with Report	No. of Rpts Received	% of Possible Reports
JAN	-	-	-	-
FEB	2	22	11	10.2
MAR	13	42	49	13.2
APR	15	50	37	10.3
MAY	18	53	38	10.2
JUN	26	87	73	20.3
JUL	26	84	91	24.5
AUG	29	74	111	29.8
SEP	21	70	62	17.2
OCT	21	68	73	19.6
NOV	13	43	37	10.3
DEC	23	74	107	28.8
			689	

TABLE V. Number (Percentage) of Reports in a 24-hr Period, Stratified by Synoptic Reporting Time (± 1.5 hr).

Time (GMT)

	00	03	06	09	12	15	18	21	Total
Ross Island	40(5)	53(7)	105(14)	140(18)	109(15)	124(17)	92(12)	84(12)	747
White Island	3(4)	2(2)	21(26)	30(37)	16(20)	5(6)	1(1)	3(4)	81
Marble Point	31(5)	35(6)	80(14)	117(20)	86(15)	94(16)	72(12)	61(12)	576
Minna Bluff	22(7)	22(7)	39(12)	56(18)	51(16)	47(15)	42(13)	35(12)	314
Asgard	45(6)	56(7)	111(14)	151(19)	115(15)	132(17)	86(11)	84(11)	780
Byrd (0021)	22(6)	31(8)	62(17)	66(18)	37(10)	56(15)	51(14)	46(12)	371
Byrd (1403)	36(5)	49(7)	95(14)	130(19)	85(12)	117(17)	97(14)	80(12)	689
TOTALS	199(6)	248(8)	513(16)	690(18)	499(14)	575(16)	441(12)	393(10)	3558

Figure 1. Automatic Weather Station site at Marble Point.

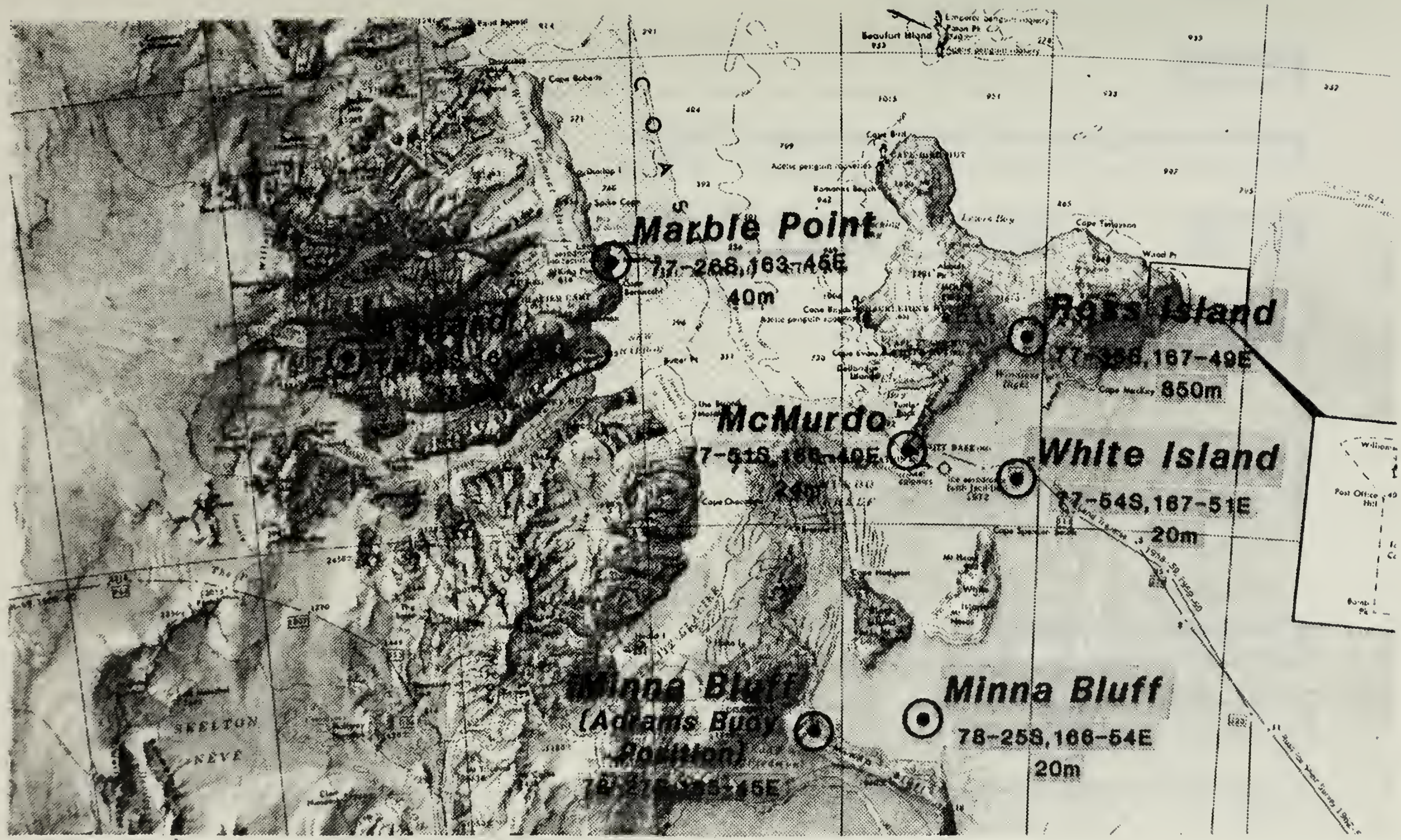


Figure 2. Locations of McMurdo and the remote-site AWS-2A and Adrams-Buoy positions.

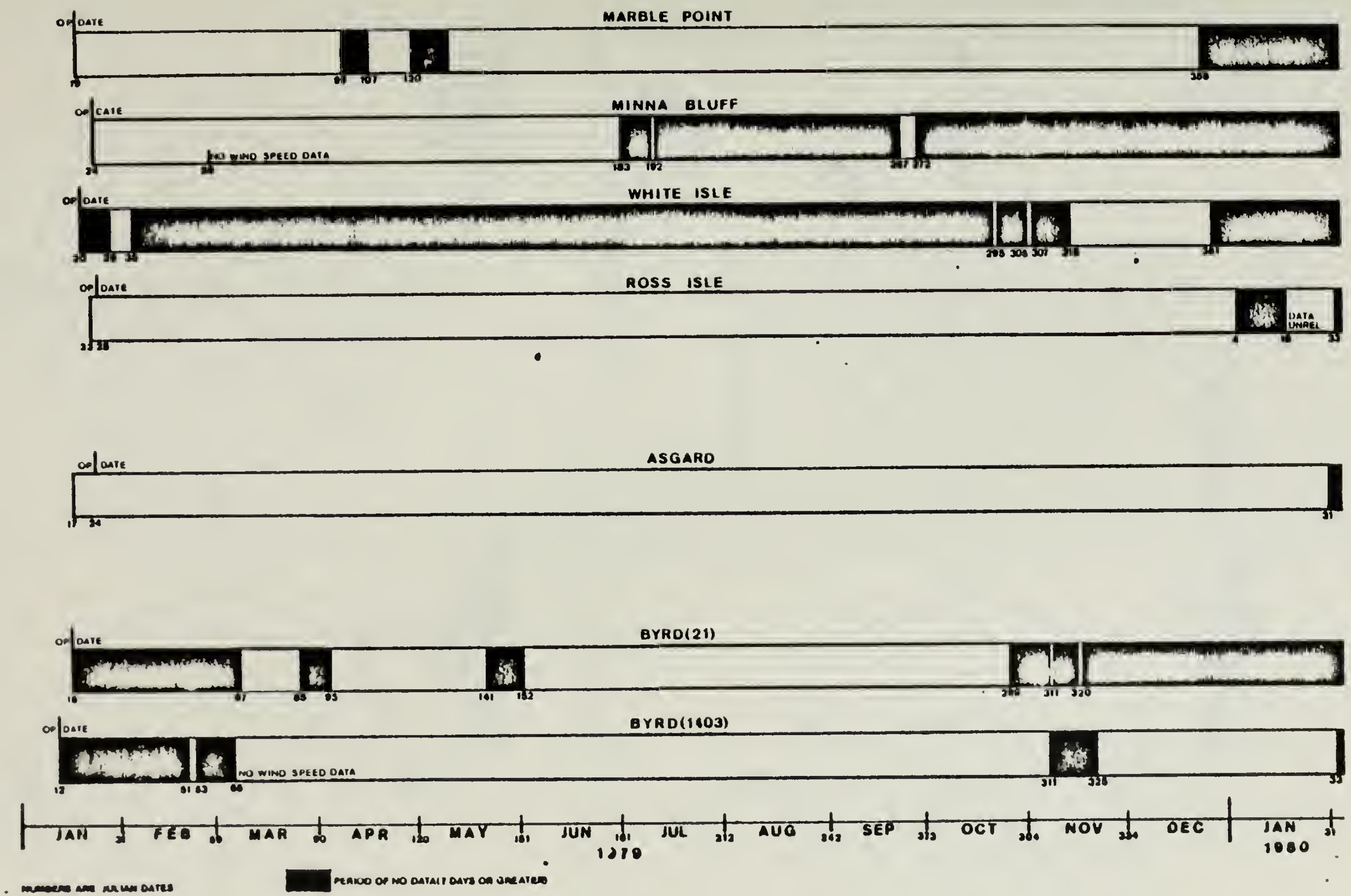
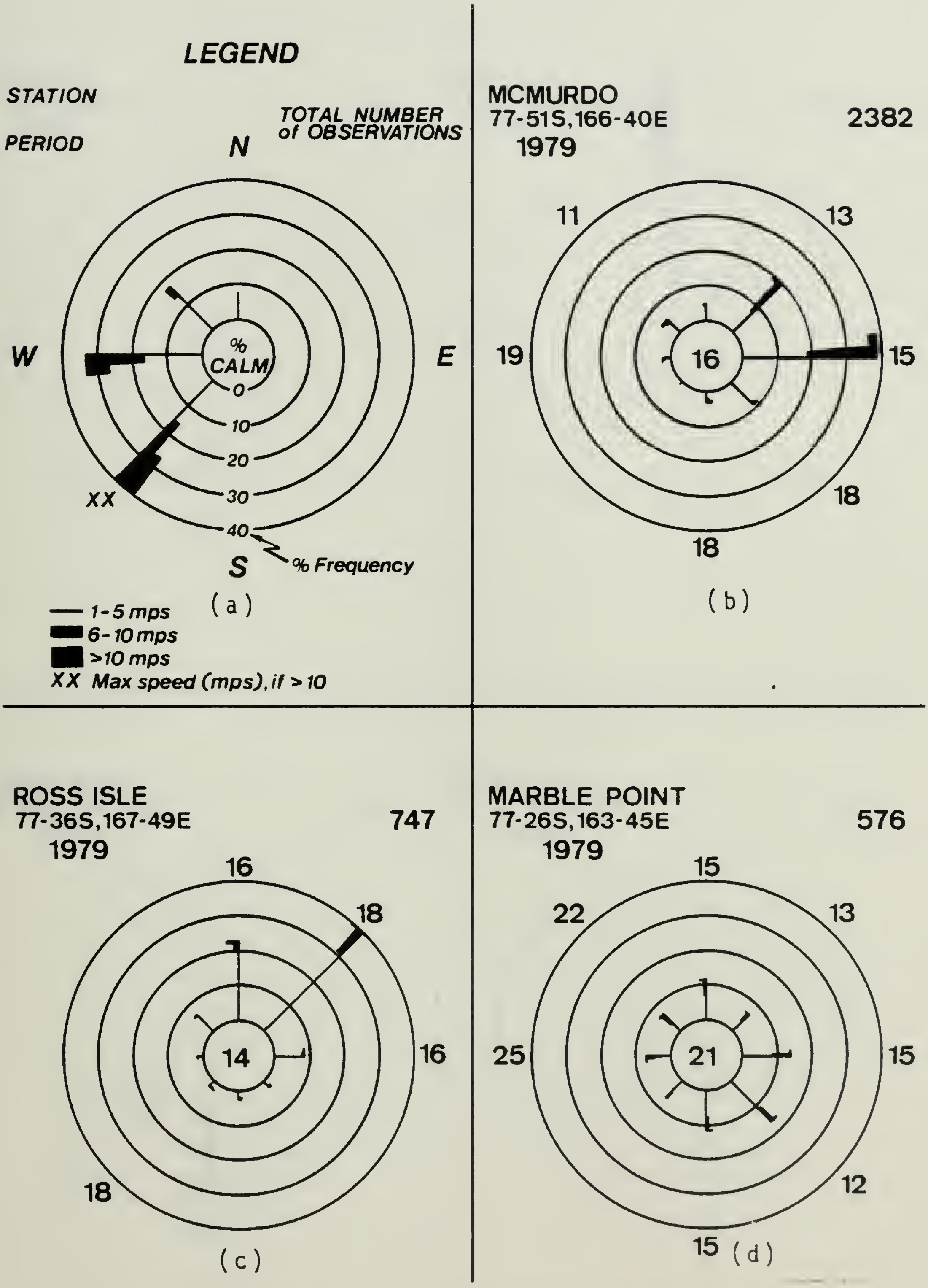
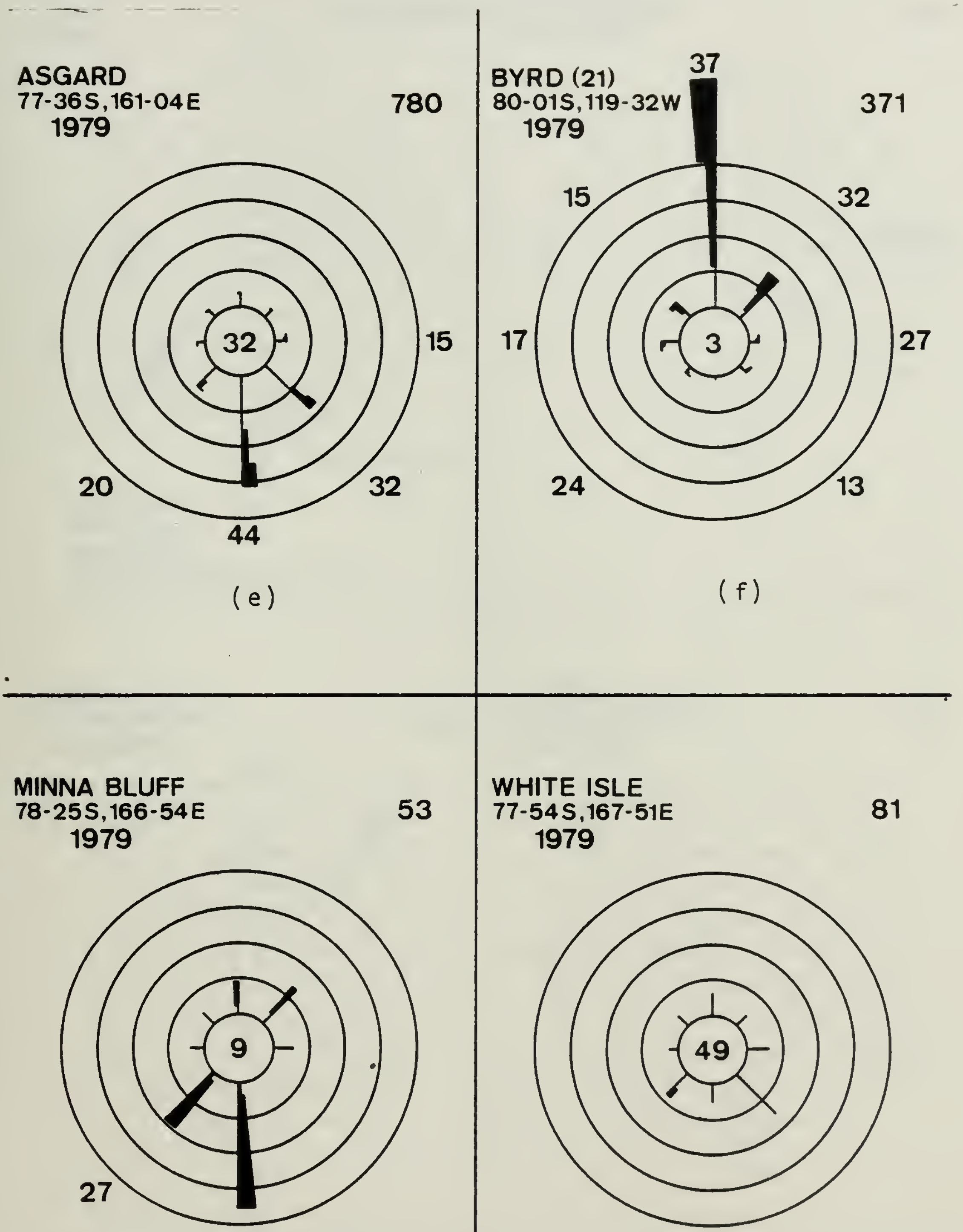


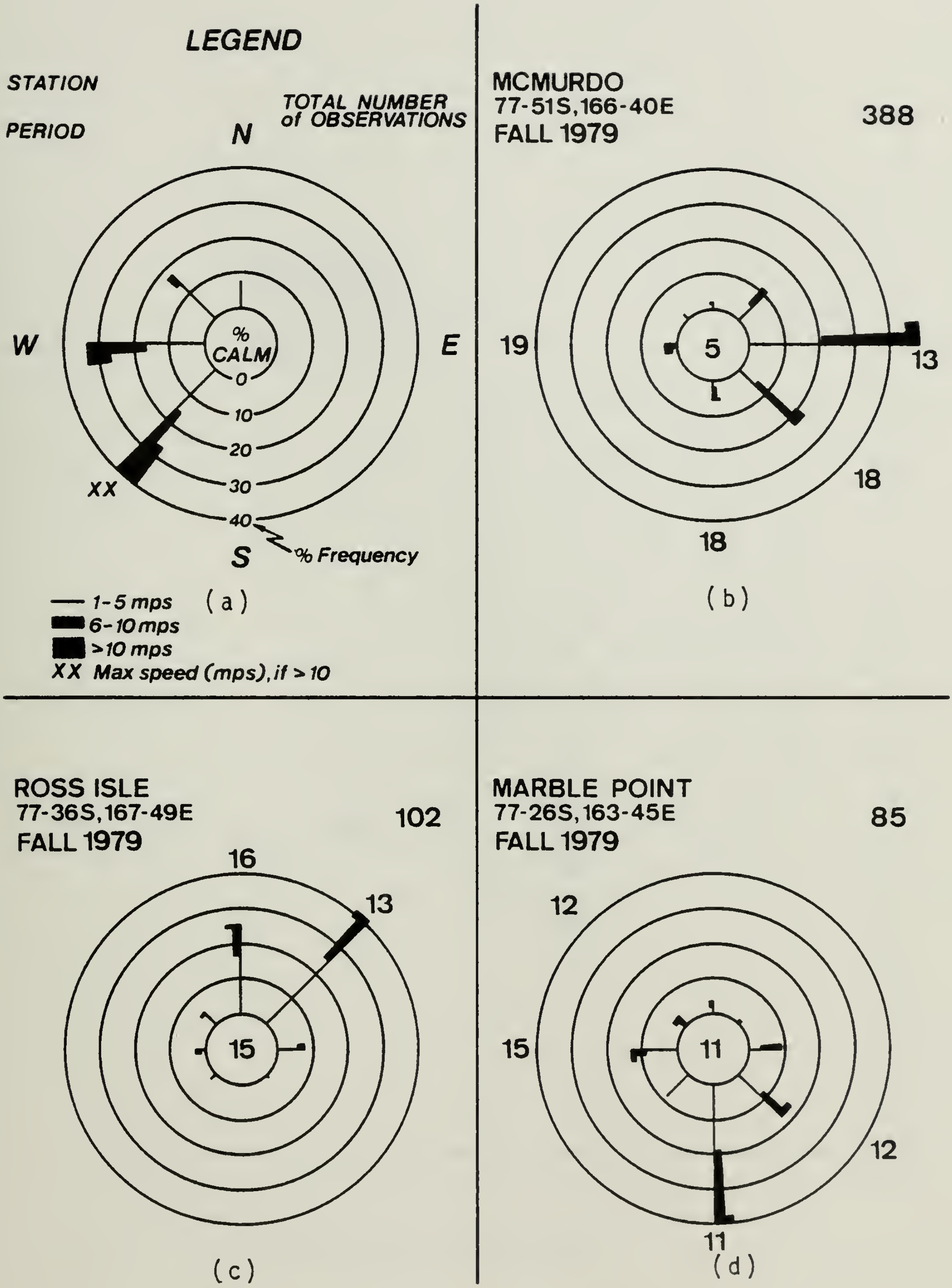
Figure 3. Operational time at the seven AWS-2A sites.



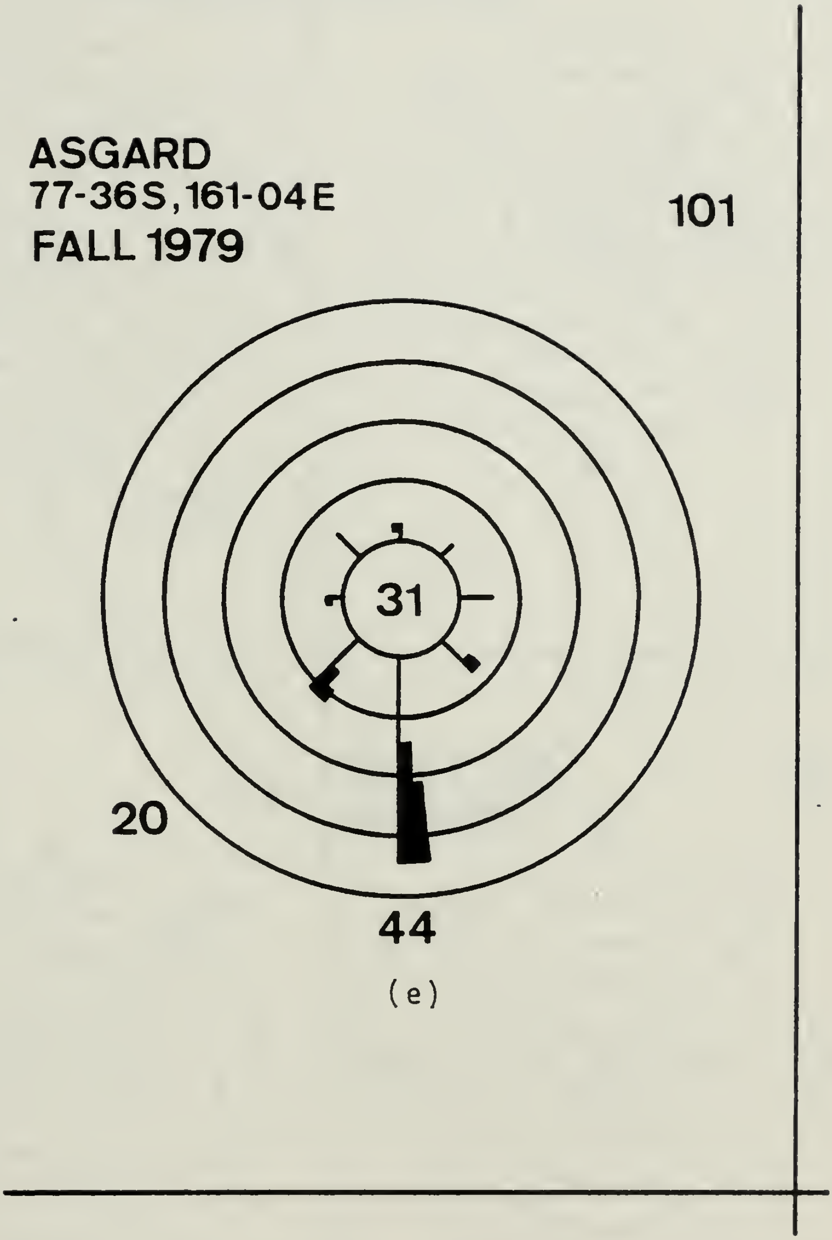
Figures 4a-h. McMurdo and AWS-2A wind roses - 1979.



Figures 4a-h (continued).

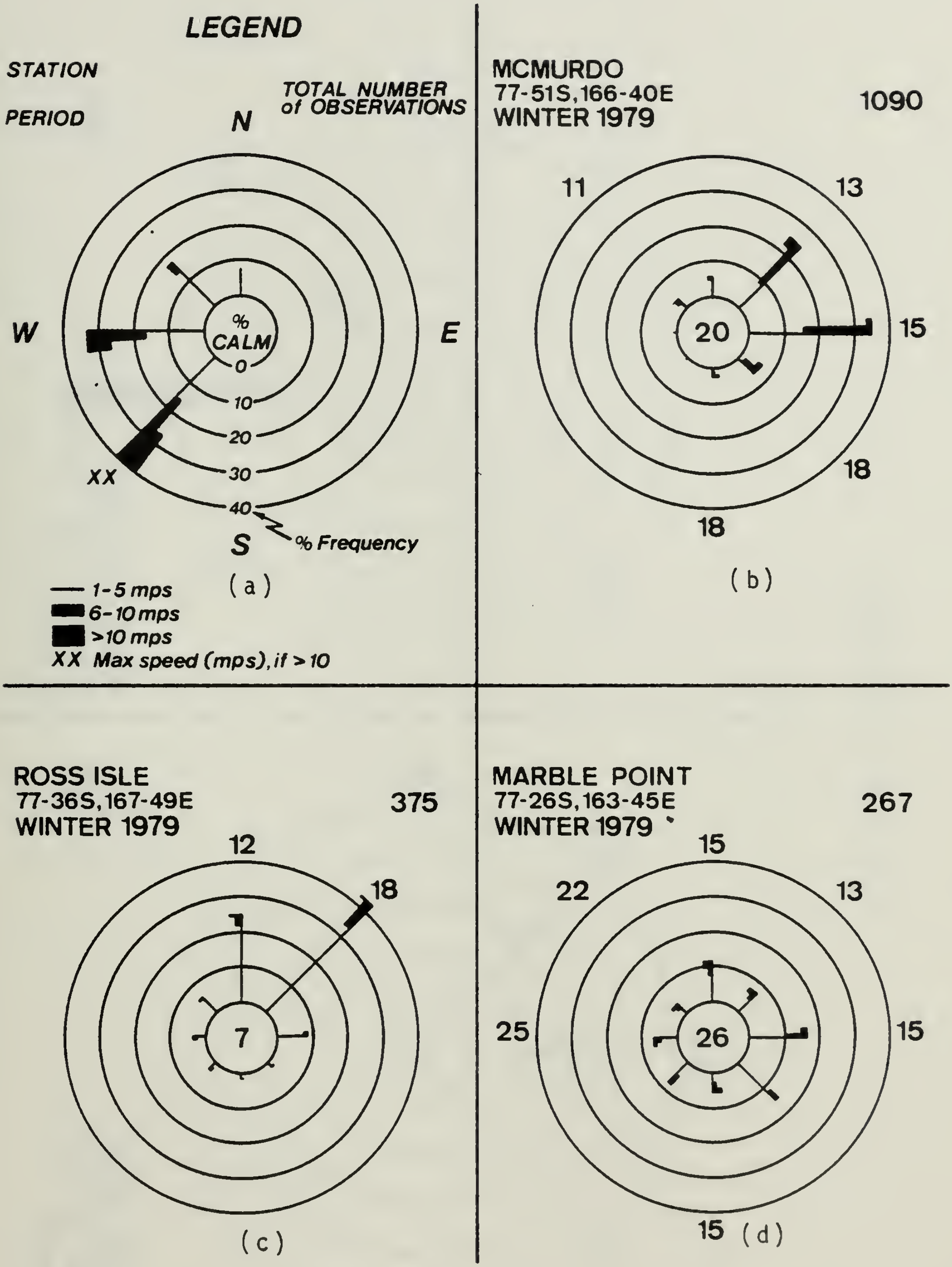


Figures 5a-e. McMurdo and AWS-2A wind roses - Fall transition 1979.

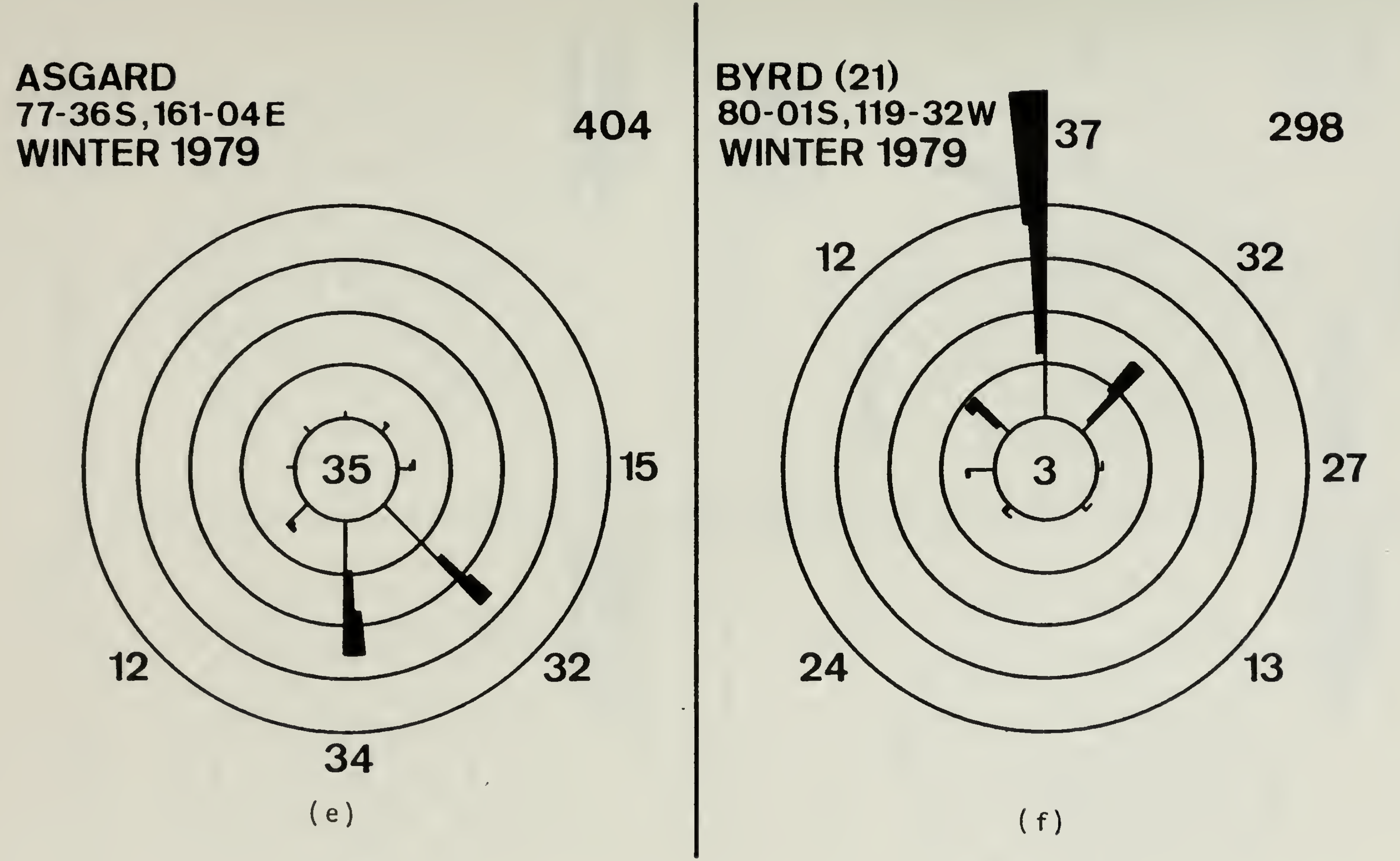


(e)

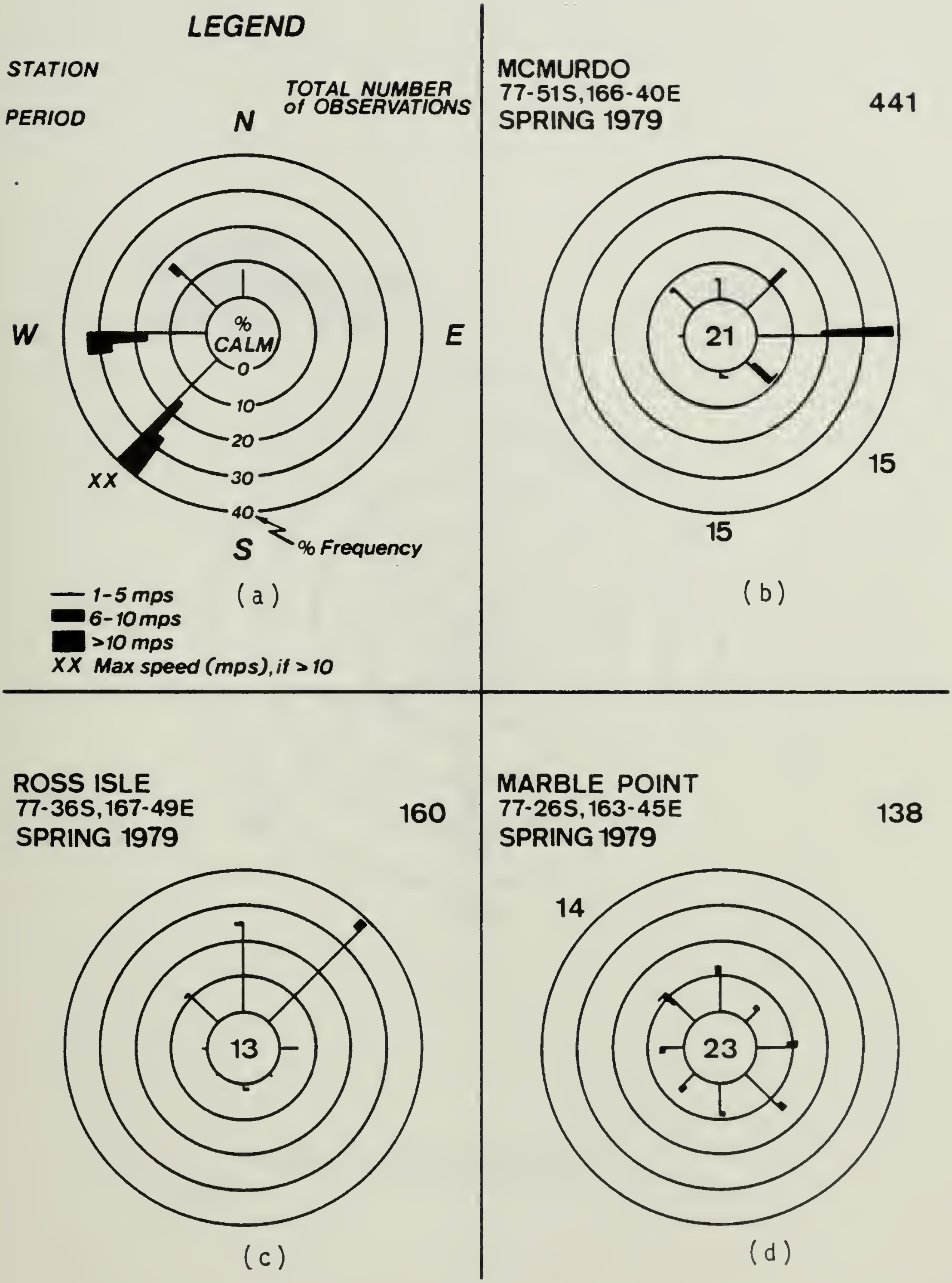
Figures 5a-e (continued).



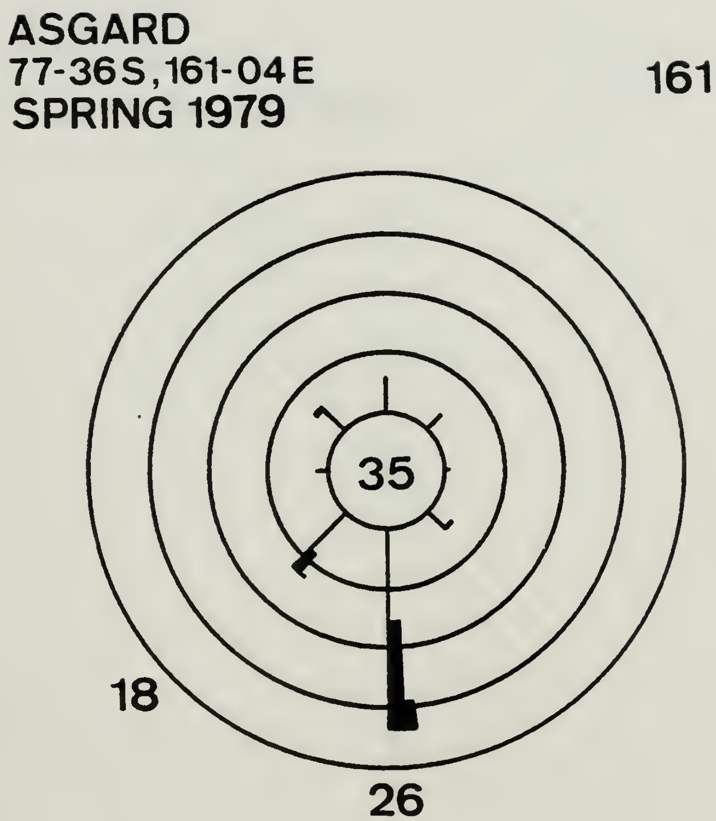
Figures 6a-f. McMurdo and AWS-2A wind roses - Winter 1979.



Figures 6a-f (continued).



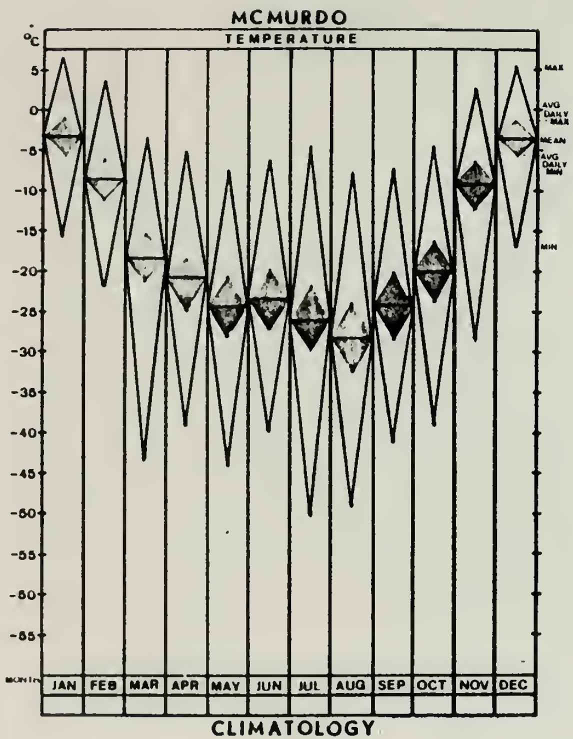
Figures 7a-e. McMurdo and AWS-2A wind roses - Spring transition 1979.



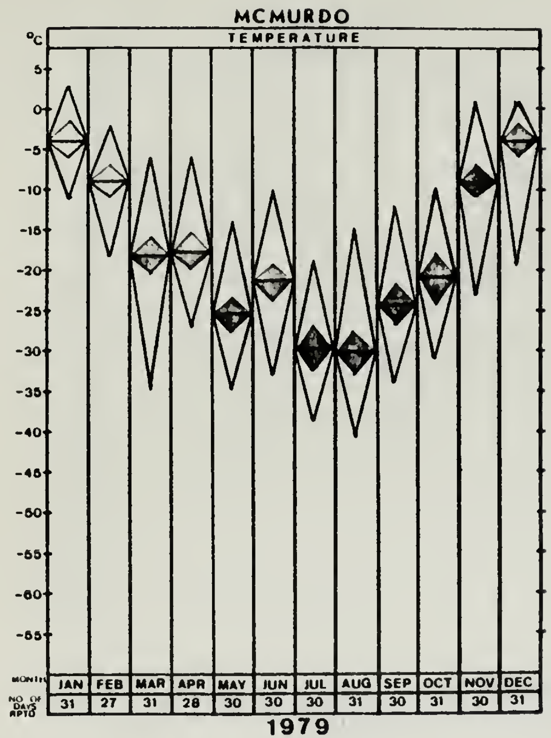
(e)

Figures 7a-e (continued).

Figure 8a. AWS-2A wind roses - Summer 1979-80.

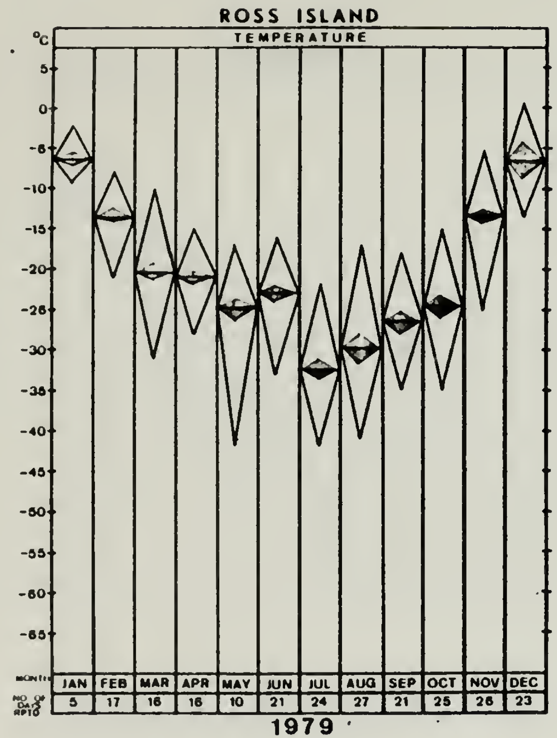


(a)

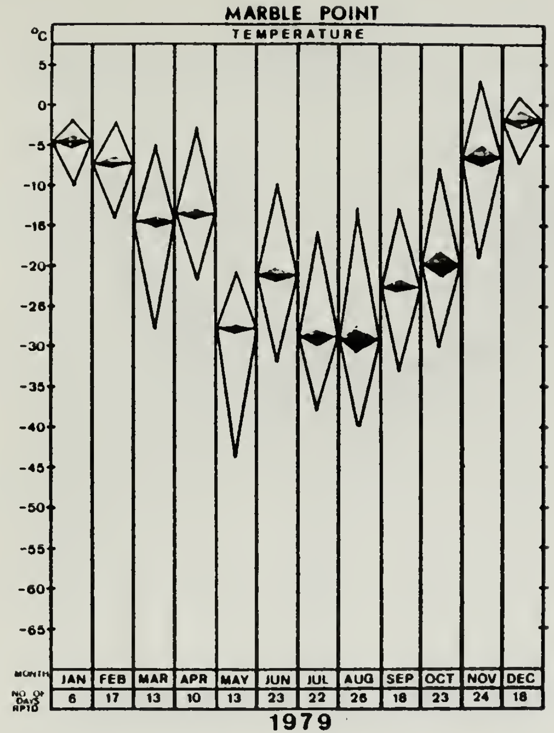


(b)

Figures 9a-i. McMurdo and AWS-2A surface temperature - 1979, and climatology.

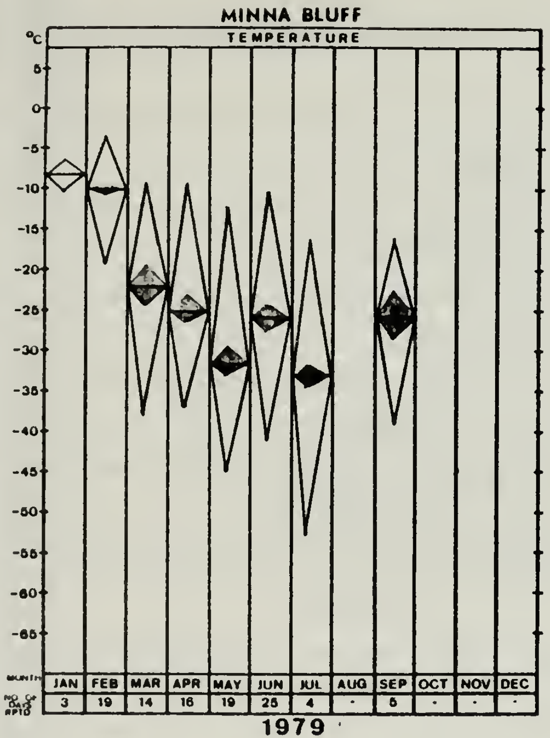


(c)

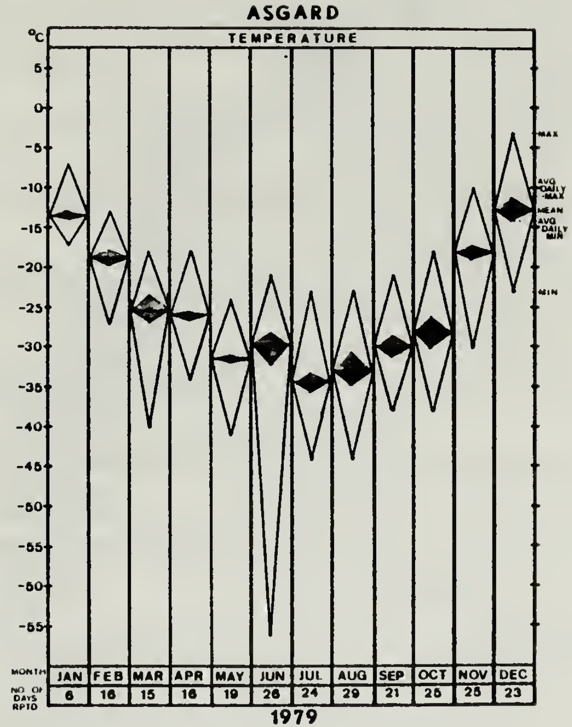


(d)

Figures 9a-i (continued).

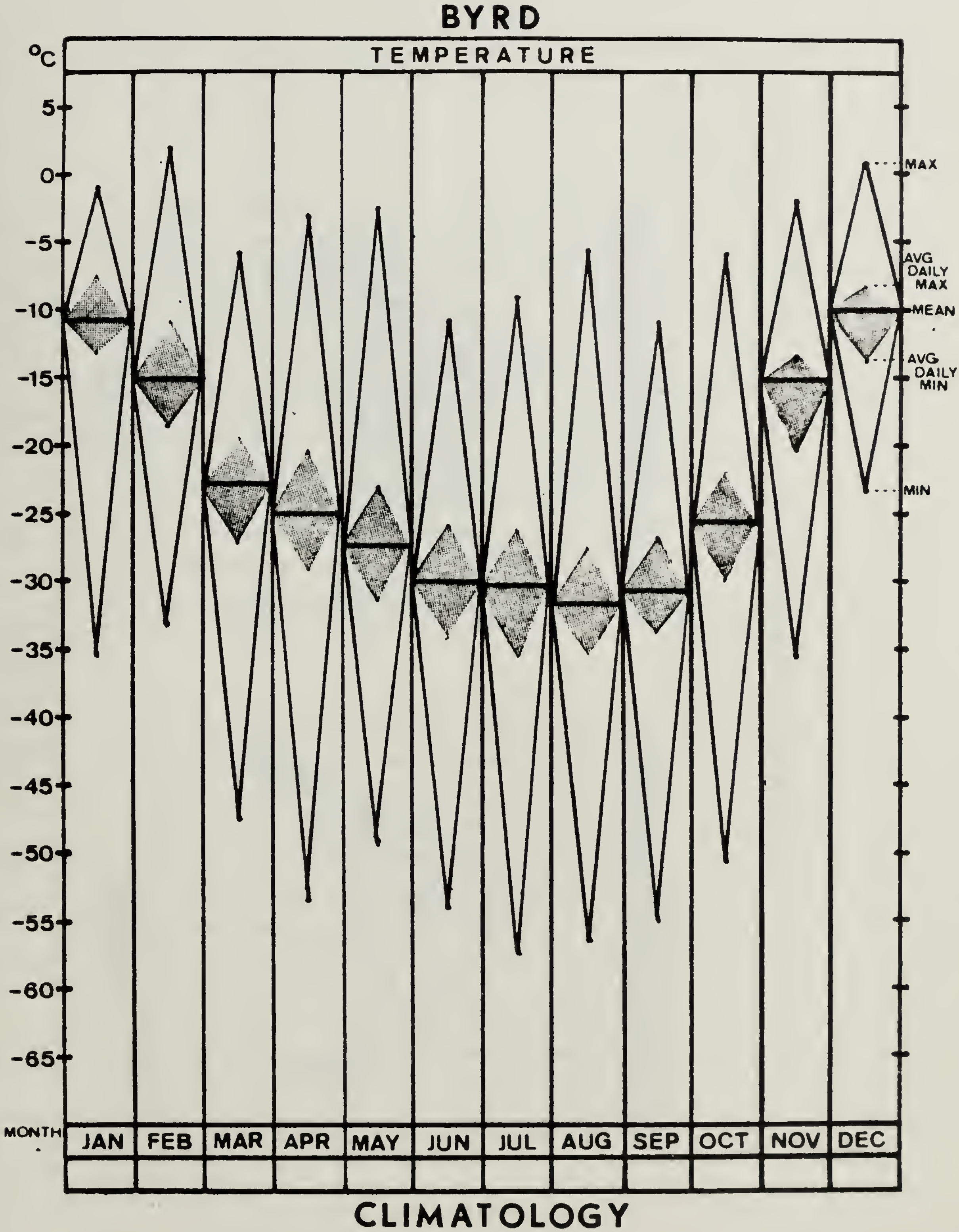


(e)



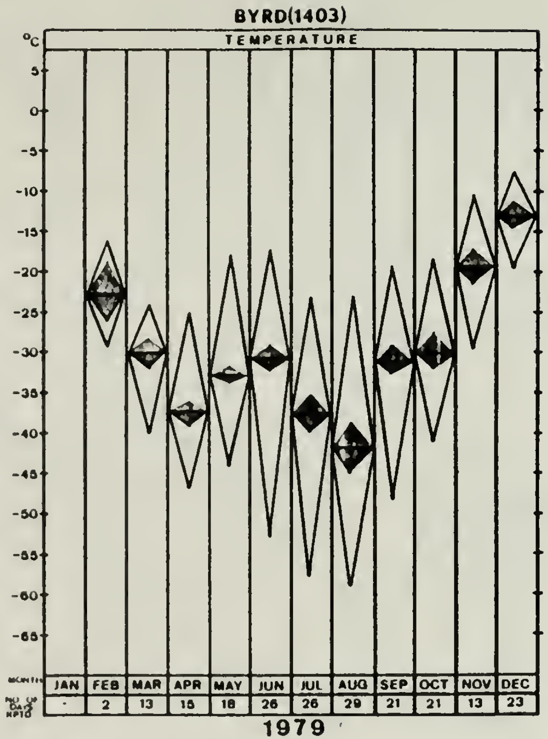
(f)

Figures 9a-i (continued).

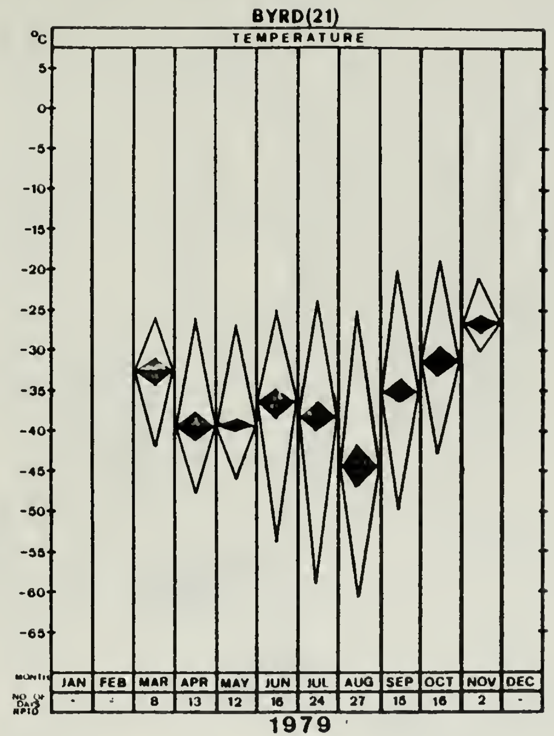


(g)

Figures 9a-i (continued).

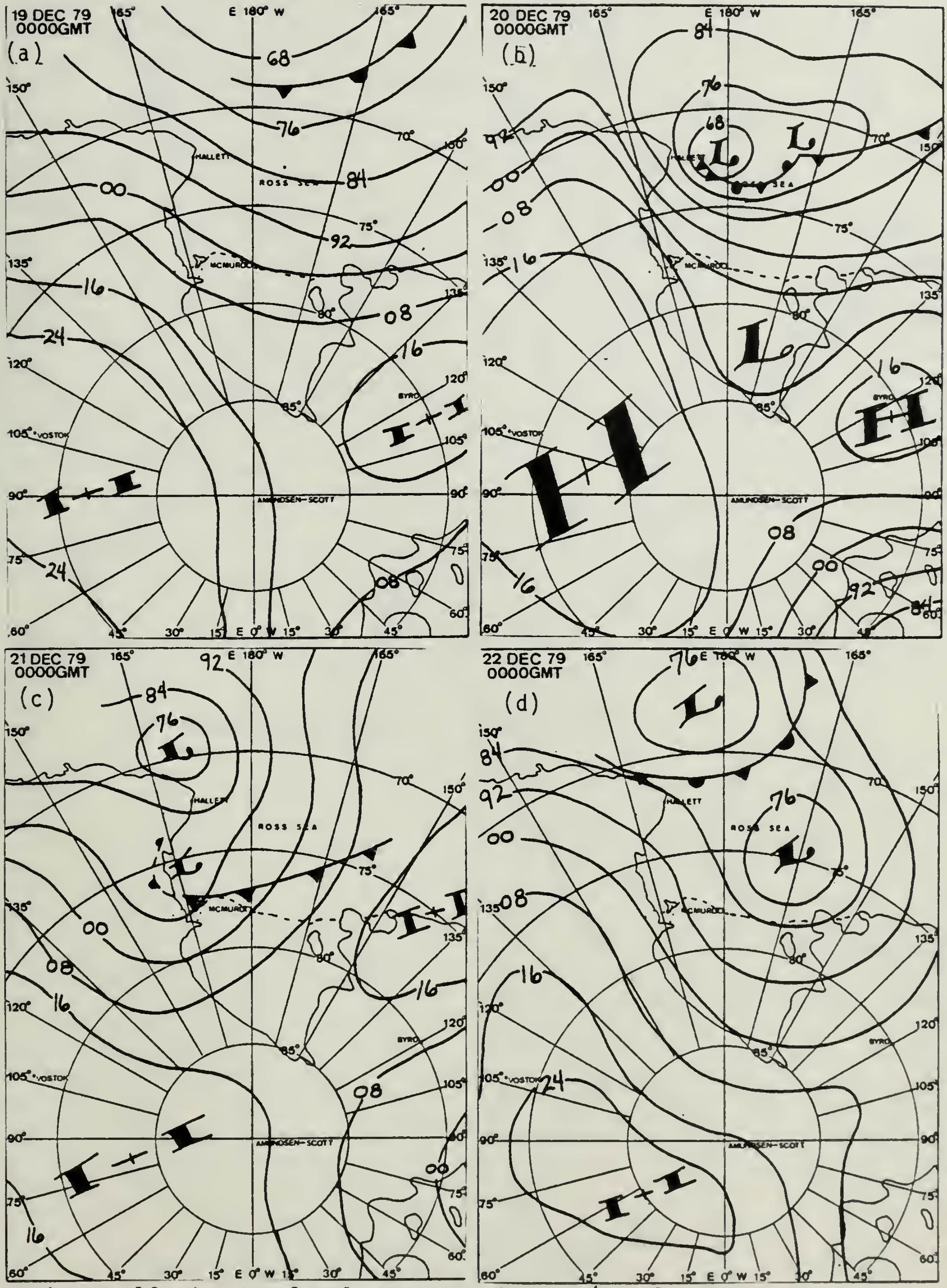


(h)

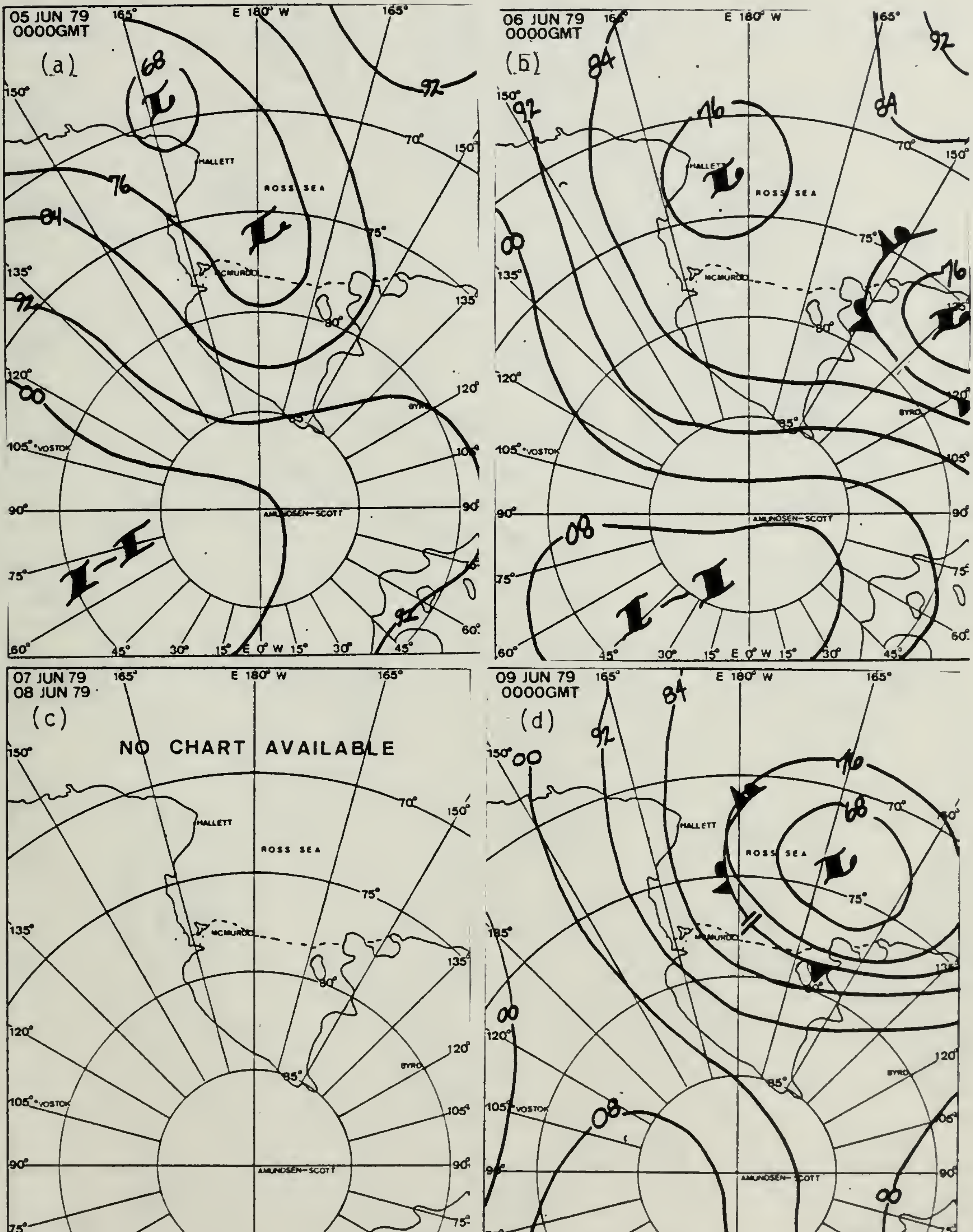


(i)

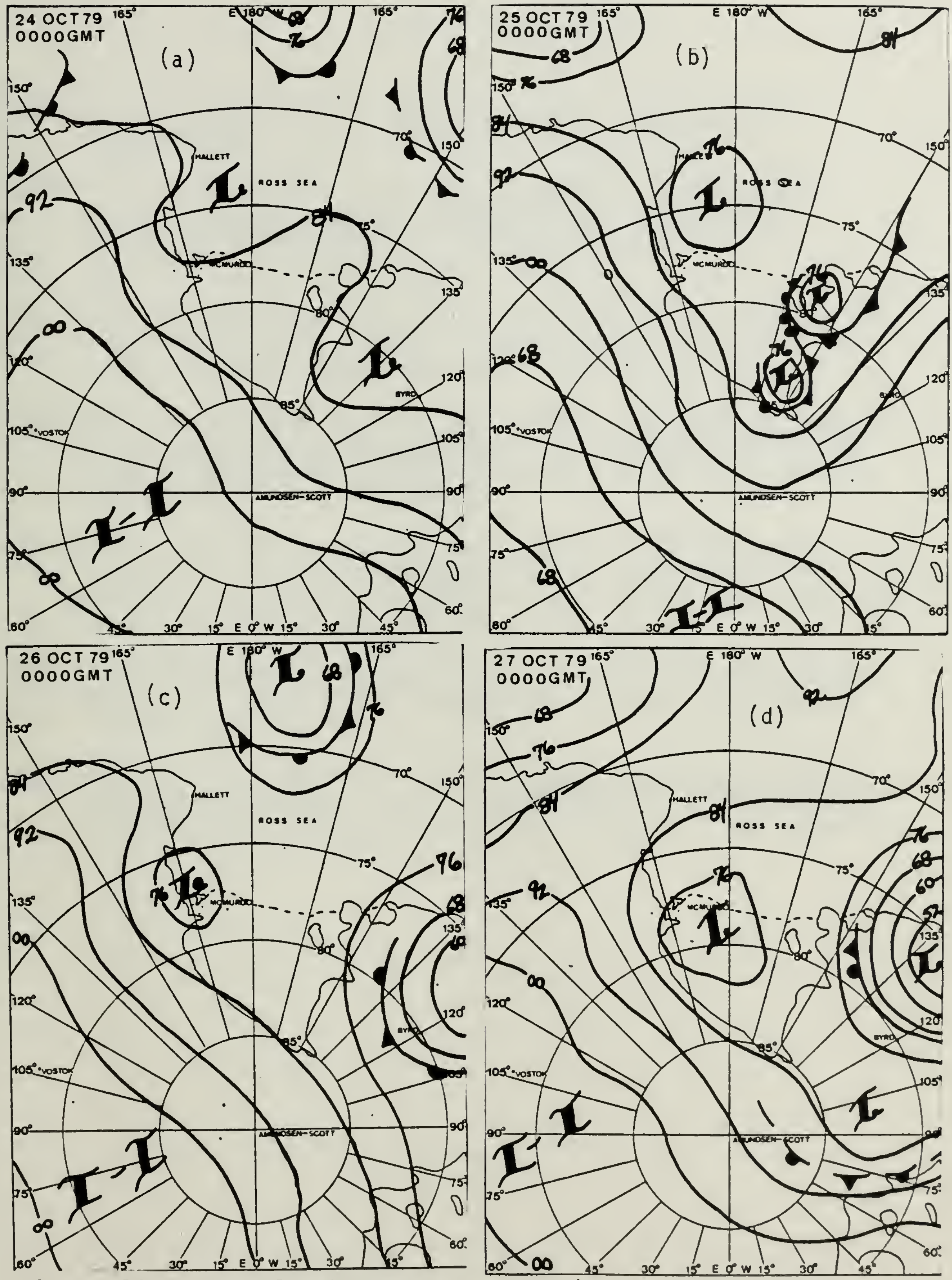
Figures 9a-i (continued).



Figures 10a-d. Sea-level pressure charts, (Naval Support Force Antarctica) 19-22 December 1979 (Summer).



Figures 11a-d. Sea-level pressure charts, (Naval Support Force Antarctica) 05-09 June 1979 (Winter).



Figures 12a-d. Sea-level pressure charts, (Naval Support Force Antarctica) 24-27 October 1979 (Spring transition).

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c.1 Analysis of Antarctic remote-site automatic weather station data for period January 1979 - February 1980.